PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

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FOR THE YEAR MDCCCLIII.

VOL. 143.—PART I.

LONDON:

PRINTED BY RICHARD TAYLOR AND WILLIAM FRANCIS, RED LION COURT, FLEET STREET.

MDCCCLIII.

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VOL. CXLIII.—PART I.

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ADVERTISEMENT.

THE Committee appointed by the *Royal Society* to direct the publication of the *Philosophical Transactions*, take this opportunity to acquaint the Public, that it fully appears, as well from the Council-books and Journals of the Society, as from repeated declarations which have been made in several former *Transactions*, that the printing of them was always, from time to time, the single act of the respective Secretaries till the Forty-seventh Volume; the Society, as a Body, never interesting themselves any further in their publication, than by occasionally recommending the revival of them to some of their Secretaries, when, from the particular circumstances of their affairs, the *Transactions* had happened for any length of time to be intermitted. And this seems principally to have been done with a view to satisfy the Public, that their usual meetings were then continued, for the improvement of knowledge, and benefit of mankind, the great ends of their first institution by the Royal Charters, and which they have ever since steadily pursued.

But the Society being of late years greatly enlarged, and their communications more numerous, it was thought advisable that a Committee of their members should be appointed, to reconsider the papers read before them, and select out of them such as they should judge most proper for publication in the future *Transactions*; which was accordingly done upon the 26th of March 1752. And the grounds of their choice are, and will continue to be, the importance and singularity of the subjects, or the advantageous manner of treating them; without pretending to answer for the certainty of the facts, or propriety of the reasonings, contained in the several papers so published, which must still rest on the credit or judgement of their respective authors.

It is likewise necessary on this occasion to remark, that it is an established rule of the Society, to which they will always adhere, never to give their opinion, as a Body,

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upon any subject, either of Nature or Art, that comes before them. And therefore the thanks, which are frequently proposed from the Chair, to be given to the authors of such papers as are read at their accustomed meetings, or to the persons through whose hands they received them, are to be considered in no other light than as a matter of civility, in return for the respect shown to the Society by those communications. The like also is to be said with regard to the several projects, inventions, and curiosities of various kinds, which are often exhibited to the Society; the authors whereof, or those who exhibit them, frequently take the liberty to report and even to certify in the public newspapers, that they have met with the highest applause and approbation. And therefore it is hoped that no regard will hereafter be paid to such reports and public notices; which in some instances have been too lightly credited, to the dishonour of the Society.

The Meteorological Journal hitherto kept by the Assistant Secretary at the Apartments of the Royal Society, by order of the President and Council, and published in the Philosophical Transactions, has been discontinued. The Government, on the recommendation of the President and Council, has established at the Royal Observatory at Greenwich, under the superintendence of the Astronomer Royal, a Magnetical and Meteorological Observatory, where observations are made on an extended scale, which are regularly published. These, which correspond with the grand scheme of observations now carrying out in different parts of the globe, supersede the necessity of a continuance of the observations made at the Apartments of the Royal Society, which could not be rendered so perfect as was desirable, on account of the imperfections of the locality and the multiplied duties of the observer.

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PHILOSOPHICAL TRANSACTIONS.

I. *Further Inquiries as to the Structure, Development, and Function of the Liver.* *By* C. Handfield Jones, *M.D. Cantab., F.R.S. Assistant Physician to St. Mary's Hospital.*

Received November 19, 1851,—Read January 17, 1852.

SINCE I presented to the Royal Society in 1847 the description which I have given of the structure of the liver, I have become acquainted with the researches of Professor Retzius, and of Dr. Leidy, and have been favoured by M. Natalis Guillot with a view of the preparations on which he grounds the opinions I noticed on that occasion.

Professor Retzius describes the hepatic ducts as forming close networks in the sheaths of Glisson's capsule, perilobular or alveolar networks; from which are given off minute lobular networks interwoven with the portal-hepatic plexuses, and constituting with them the substance of the lobules. These plexuses are described as consisting of anastomosing tubes which are formed of a basement or limitary membrane, like those of other glands, and in these tubes I presume Professor Retzius considers the hepatic cells to be lodged.

Dr. Leidy's account is very similar, at least as far as relates to the structure of the lobules; he figures the cells as lying within tubes, which have walls of basement membrane, and are two or two and a half times the diameter of the secreting cells.

In M. Natalis Guillot's preparations, the injection thrown in by the hepatic duct is seen lying in the interspaces of the capillary blood-plexus, and occupying the whole extent of the lobules. The view of these anatomists is in great measure accepted and confirmed by Dr. Carpenter*: he has satisfied himself that a system of canals prolonged from the bile ducts exists in each lobule, but is unable apparently to discover the basement membrane, which Retzius and Leidy agree in describing. The testimony of Muller, Weber, and Kronenberg is also to the same effect; they describe the hepatic ducts as commencing in very fine networks interlaced with the capillary networks between the portal and hepatic veins. And lastly, all the now

* *Vide* Art. Secretion, Cyclop. of Anat. and Physiol.

mentioned authorities are but corroborators of the original description given by the founder of the anatomy of the liver, Mr. KIERNAN, so that one can scarce withhold assent from the doctrine, that a "lobular biliary plexus" really exists*.

To advance a contrary opinion in the face of the testimony of so many and so eminent authorities, can hardly be judged other than presumptuous; yet if it appear that the ascertaining of truth is my sole object I shall not fear this censure, as well knowing that candid minds are glad to confront their own views with all possible objections, which serve as tests to detect the alloy of error, and to bring forth into clearer show the lustre of the real gold of truth.

I will mention first two results I have obtained by the method of injection, which go to confirm the views of those who maintain the existence of a lobular biliary plexus, and are, therefore, opposed to that which I have supported. In reading the description given by chemists of the mode of obtaining the acids of the bile, the cholic, and the choleic, it occurred to me, that the same reagent, the acetate of lead, might be employed to produce a precipitate with the bile while still contained in the ducts.

I tried this first with a Guinea Pig, injecting the ductus com. choled., immediately after the animal had been killed, with a saturated solution of the salt above mentioned. This produced a most abundant precipitate in the gall-bladder, and along the ducts, even to those of extreme minuteness, rendering them visible to the naked eye as ramifying white lines or streaks. In several parts there was seen springing from the sides of ducts running in fissures or small portal canals, a minute plexus consisting apparently of short straight vessels, uniting at nearly right angles with each other. When very thin slices of parts presenting this appearance were minutely examined, it was manifest that these vessels exactly occupied the intercellular spaces; they had no membranous walls, and seemed to consist solely of injection forced in between the cells. Their diameter was very uniform $\frac{1}{10,000}$th of an inch, and the side of the meshes exactly equalled that of the cells, about $\frac{1}{1000}$th of an inch. They originated directly from the ducts of fissures or canals, and not from any such network as Professor RETZIUS describes. This appearance of a plexus was very partial, it occurred only in certain spots, and not, as it appeared to me, in those parts where the ducts were best injected; but was seen as a border of varying width along those portal canals where extravasation had manifestly occurred. I repeated this experiment with the liver of the Sheep, and obtained a result which appeared very striking. The lobules, where the injection had penetrated, presented in their whole extent the appearance of a plexus. This plexus was very different in its aspect to the partial one obtained by injection of the Guinea Pig's liver; it consisted not so much of distinct vessels, but of spots, patches, and very fine streaks, coalescing irregularly together. I am inclined to consider the result in both these cases as produced by the action of the acetate of lead upon the albuminous plasma lying between the cells;

* KÖLLIKER, however, denies the existence of a biliary plexus, and describes the ducts to terminate nearly in the same way that I do.

this agent, when added directly to a portion of parenchyma, produced no marked effect on the cells, rendering them only somewhat more granular, but coagulated a considerable quantity of the free interposed material.

Having described these two results, which, though quite capable, as I conceive, of being otherwise interpreted, appear to support the opinion of there being a lobular biliary plexus, either containing and enclosing the cells in its passages, or interposing its tubes between them, I now proceed to detail those observations which I have recently made, and which after candid consideration do still confirm me in the opinions I formerly expressed, and also throw some light on the mode in which the efferent mechanism may be conceived to perform its function.

The class of Fishes I have found, as before, most easy of examination, and most productive of results, and I would ask inquirers into the subject to direct their attention carefully to these examples. My later dissections have confirmed entirely the description given in my last paper; they show the ducts running a long course with comparatively little branching through the parenchyma, encrusted by it on every side, and terminating without forming any such connection with it as to envelope and surround it. Often the ultimate branches appear as tracts of finely granulous or amorphous matter, in which, when it is broken up, delicate nuclei are discerned: this is perhaps the most common condition, but there are two others which I have most unquestionably observed, and which *quoad* the physiological action of the parts are of great interest. In one of these, the least common, the nuclei are not obscured by the granulous matter, but are distinctly visible, as I figured them in my last paper from the liver of the Perch; they seem to constitute the chief part of the wall of the ductule, and lie close together in a scanty amount of granulous basis substance. This condition, unusual in Fishes, is ordinary in Mammalia; of its import we shall subsequently attempt to give some interpretation. In the other condition, the ducts, not only the terminal, but even the smaller trunks, are *filled* with a pellucid opaline material, in which are imbedded vesicles containing a fluid of the same aspect; often the vesicles are exceedingly numerous, and seem to replace the opaline material; it may indeed be said that the two exist in inverse ratio, and that the one is developed from the other. It seems most probable that the fluid in the interior of the vesicles is bile, and that by their dissolution it is set free in the efferent passage.

A very frequent appearance is, that in the interior of ducts the outlines of vesicles are discerned more or less distinctly in various parts amid translucent free material. The size of the vesicles varies a good deal, from $\frac{1}{3333}$rd of an inch to $\frac{1}{1000}$th of an inch; they seem of exceeding delicacy, but resist sufficiently to alter each other's shape by mutual pressure, and to float about in the water for a short time after they have escaped from the duct. I have called them vesicles, as they do not commonly appear to contain nuclei; but in one instance I found that nuclei did exist in their interior, so that they may sometimes no doubt attain the rank of cells.

An important point to be noticed with regard to the ultimate and penultimate ducts is, that they appear to be *filled* with their epithelium; the central passage must

be extremely small, and cannot be actually discerned: this surely is not the condition of a mere channel of passage, a mere outlet for an already elaborated fluid; it surely betokens an active process of attraction, and probably chemical transformation to be going on.

The truth of this remark will be more apparent if we compare the condition of the epithelium of the ultimate or elaborating ducts with that of the large trunks; in the former it has the characters we have just described; in the latter it consists of a simple pavement of short columnar particles; the one is in the condition of the ureter or any simple mucous surface, the other in that of the deeper parts of the gastric or renal tubule.

I subjoin here the details of some examinations I have made in this class of animals, believing that I cannot in any better way convey an idea of the various appearances observed. In a Pike (*Esox lucius*), to whom I had given a dose of calomel, there was observed a peculiar condition of the ducts which seems worth noticing, although there was no reason to regard it as in any way produced by the drug. Many of the larger ducts were obstructed by a concrete deposit in their interior, which, viewed by direct light, was of a glistening white, and probably consisted of cholesterine or some bile-derived matter. At the obstructed parts the duct was considerably narrowed, while beyond it in the direction of ramification it was greatly dilated, sometimes to more than twice its natural magnitude; the distended part forming a pouch of somewhat globular form, into which small absorbing ducts opened; these must doubtless have existed, though they seemed in some cases to be more or less obliterated. The wall of the dilated part was greatly thickened, chiefly by an increase of its fibrous investment; within this a homogeneous tunic was distinctly discernible, supporting a layer of epithelium, which was, I believe, of secreting function, and not a mere lining. The fluid contained in the dilated part was in some instances of a decided bilious colour, which probably depended on its having become concentrated by being retained in the canal longer than usual. The obstructions in the ducts had occasioned no noticeable change in the parenchyma; it was tested for sugar by Trommer's method, and gave distinct evidence that this was present.

About the middle of February I examined a Roach (*Leuciscus rutilus*) very full of ova, the parenchyma of the liver was of a pale red tint and semitranslucent; it consisted of nuclei, granular matter, and multitudes of delicate semitransparent vesicles packed closely together; one or two tablets of cholesterine, and some biliary deposits were observed in it.

One part of this liver formed a long thin tongue, and this viewed without being cut exhibited a beautiful capillary network perfectly injected with blood; the vessels formed long narrow meshes; and it was especially observable that, while there was scarcely any oil to be seen in other parts of the parenchyma, there were little groups of small oil-drops seated at intervals all along the sides of the vessels, as if it had just exuded from them. The ducts, when dissected out, were seen most perfectly; all the elaborating ones were crowded with delicate pellucid vesicles, varying a good deal in size,

and lying together with nuclei imbedded in amorphous matter; similar vesicles and more distinct nuclei were seen in the larger ducts up to a diameter of $\frac{1}{114}$th of an inch; some biliary deposits were seen adhering to the exterior of the ducts, which in this instance were not dilated.

About the same time I dissected another Roach whose abdomen contained but little roe, and who had been dosed, fifteen hours before death, with two grains of blue pill.

The spleen contained several groups of yellow corpuscles; some of the larger were surrounded by a homogeneous envelope; they consisted of various-sized corpuscles of about the diameter of blood-globules, but more spherical and more opake, as well as more brightly and differently coloured. Coloured corpuscles were sometimes seen quite alone, sometimes a very few together; such were not surrounded by envelopes.

The liver was of the buff-yellow colour, which indicates a fatty condition; its parenchyma was loaded with oil, which was in the state of small drops that became detached and floated freely about in the field of view; I satisfied myself of the existence of the pellucid vesicles that were so numerous in the former, but they were not present in nearly so great numbers; the parenchymal substance presented the appearance of imperfectly formed celloid particles coalescing together in a plexiform manner; they were surrounded and enveloped in oily matter. In some parts small biliary deposits were also observed.

On dissecting the ducts out, I found some of the trunks extraordinarily dilated into great pouches; the smaller branches, and especially those nearly terminal, were not enlarged, or not much; but they and all the ducts, even the trunks, were stuffed with their epithelium, which was at first scarcely discernible, the tubes appearing as if filled with a pellucid matter; but when one was ruptured and the epithelial contents escaped, the vesicles, nuclei and amorphous matter came clearly into view.

On examining closely the large ducts, especially after steeping them in solution of bichloride of mercury, it was well seen how their epithelium had encroached on their cavity, so as in some parts to have closed the canal completely; this obstruction had doubtless occasioned the dilatation of the ducts into pouches, which may also have been promoted by the inordinate growth of the epithelium in those parts. The dilatation of the ducts was not confined to those now described; many of the smaller were also affected, so that branches traced in the direction of ramification actually enlarged instead of diminishing, and this manifestly depended on their own stuffing, and the obstruction towards the outlet. In some ducts the vesicles were very apparent, crowded together in groups; in others there was scarce anything to be seen but an amorphous and fluid matter. Neither this liver nor that of the preceding yielded me any evidence of the presence of sugar.

A third Roach was dosed with $1\frac{1}{2}$ grain of blue pill twice, an interval of seventeen hours being allowed to elapse between the doses; it was killed sixteen hours after the last. It contained large masses of ova. The liver was pale, semitranslucent, and contained a good deal of blood in its vessels; its parenchyma consisted of nuclei, granulo-amorphous matter, and very delicate granular globules; there was very little oil, and

not any biliary deposits were seen. The gall-bladder was very full of bile. The ducts dissected out appeared occasionally distended, but to a much less extent than in the preceding instance; the epithelium in the larger ones consisted of columnar particles, which viewed *in situ* gave a mosaic or pavement-like appearance; in those of next size the epithelium was in great part vesicular; and in those of smallest size it chiefly consisted of nuclei and amorphous matter, with a few incipient vesicles. In several of the ducts the canal was very much narrowed by the epithelial growth.

These details, though rather minute, are not, I think, devoid of interest, especially as illustrating the actively growing nature of the epithelium of the ducts. With regard to the condition of the parenchyma generally I have nothing to add to my former observations, except that I have usually noticed that when the ova are considerably developed, and form large masses occupying a great space in the abdomen, the quantity of oil in the liver is greatly diminished; it seems to be diverted from its usual place of deposit, and appropriated to the formation of the growing structures.

Development in Fishes.

I now proceed to describe the development of the liver in this class, in which it is observed under very favourable circumstances, as the stages succeed each other slowly, and the transparency of the tissues enables the observer to conduct his examination with little injury to the specimen. In a young Perch (*Perca fluviatilis*), which had recently quitted the ovum, and in which the circulation was distinctly visible, I found the vitelline sac attached to the body, but not included by abdominal walls; there was no intestine yet formed, nor any trace of liver. In the vitelline sac there was seen a smaller one lying near the anterior extremity just behind the heart; this contained a more highly refracting matter than that in the larger vitelline cavity. The next day I observed that the heart was covered in by a strong membrane which passed over the yolk-sac, and was continuous with the inferior vertical fin, and doubtless with the sides of the body, thus closing in the abdominal cavity.

An intestinal tube was now formed, and an oral cavity, but the intestine did not communicate with it, nor had it any anal outlet. By the morning of the next day the intestine had extended quite to the throat, and was enlarged into a fusiform dilatation corresponding to the stomach, while a narrow space intervened between it and the vertebral column. By the evening of the same day the continuity of the intestine as œsophagus into the throat, and the cavity of the mouth was most distinct. I observed a short blind offset passing backwards and upwards towards the vertebral column from the stomachal dilatation; this was evidently the rudiment of the air-bladder. A day later the plicæ of the intestine had begun to appear; its walls were very thick, there was no trace to be seen of liver, or of renal glands. Peristaltic movements were observed in the intestine twenty-four hours later; the duct of the air-bladder was now of pretty good length, but scarcely appeared to be hollow.

Two days from this time the intestine was sufficiently consistent to admit of being dissected; its surface was still more plicated; its posterior fourth was separated from

the anterior portion by a kind of annular constriction, thus marking off the future large intestine: the walls presented some appearance of developing muscular fibre.

Three days later the cardiac orifice of the stomach presented a more marked constriction, separating it from the œsophagus; no liver nor kidneys were yet formed. I observed at this time that the black pigment was deposited directly as such, constituting globules and streaks of various size, and not previously elaborated and gradually formed in cells. The next morning, that is ten days from the date of the first observation, I observed a mass at the anterior part of the abdomen, extending on a level with the anterior part of the yolk-sac to some distance behind it; this was doubtless the rudiment of the liver; it consisted of granulo-amorphous matter, and was traversed by ramifications of a vessel which spread itself over the yolk-sac; this vessel was a branch given off from the cardinal vein near the anus; it ran along the lower border of the intestine, and after ramifying on the yolk-sac and on the liver, joined a vein entering the heart. A rudiment of the gall-bladder, in the form of a small transparent vesicle, was also observed; the lower end of this appeared to dip down towards the intestine.

On the succeeding day I noted that the parenchymatous mass of the liver was quite distinct, and that the transparent vesicle, the future gall-bladder, adhering to it, had enlarged, but without having yet formed any communication with the intestine. I dissected the intestine out, and saw clearly that there was no protruding of its parietes as if the liver were a development from it. The constriction separating the small and the large intestine was very marked and the appearance of the two very different, the former being thrown into many folds, the latter being more smooth. On the evening of this day I observed the liver having the same shape as in the adult fish, the anterior border being notched; it was traversed by a pretty close plexus of capillaries, and contained the remains of the small yolk; it consisted of granulous and oily matter imbedding delicate vesicular cells. Two days later the parenchyma of the liver had nearly the same aspect; its cells were probably more numerous; they varied in diameter $\frac{1}{3000-600}$th of an inch, and were imbedded in oily and granulous matter. The gall-bladder was still a transparent vesicle, in diameter $=\frac{1}{144}$rd of an inch, formed by a homogeneous tunic and having some traces of a lining epithelium; its shape was somewhat pyriform, the small end being directed upwards or anteriorly. It was distended by a transparent fluid, which as yet had no outlet. Two days after I noted that the yolk-sac imbedded in the parenchyma of the liver had become very small, and that the gall-bladder was elongated and tended downwards and backwards towards the intestine. The succeeding day the narrow extremity of the gall-bladder was still more elongated; it tended still more downward, and adhered by its apex to the stomach.

After having carried my observations thus far my stock of young fish died, and I was unable in consequence to follow the further progress of development regularly, but after the lapse of about six weeks I procured some minute fish very similar to those I had before been observing. The result of my examination of these was as

follows. The liver appeared as a small grayish mass, consisting of delicate vesicular transparent cells, mingled with granulous and oily matter, not in great abundance. The gall-bladder was large, distinct, transparent, full of a colourless fluid, and lined by a distinct epithelium; it had a short duct communicating with the intestinal canal, from which an offset turned up to the mass of the liver; this proceeded but a little way, and terminated by forming a small tract of nuclear particles. The resemblance between the structures observed in these young fish and those whose development I have traced above was so close, that I feel quite justified in concluding that the former presented the ultimate stage of the developmental process, and therefore I venture to offer the following summary as descriptive of the formation of the liver and its excretory apparatus in Fishes.

(1.) The intestine is formed before there is any trace of liver.

(2.) The parenchyma of the liver and a vesicle, the rudiment of the gall-bladder, are first formed; the small yolk mass lies in the substance of the liver.

(3.) The gall-bladder assumes a pyriform shape; its narrow end approaches the intestine and opens into it, while from a part of its extent hepatic ducts are developed that extend into the liver.

(4.) The contents of the gall-bladder at first are not bile, but probably a weakly albuminous fluid; this continues to be the case for some time after the parenchyma of the liver is completely formed.

In my examination of the livers of Reptiles I have been more successful than formerly, and entertain no doubt of their being constructed exactly after the same plan as those of fish. The parenchyma in the Common Frog (*Rana temporaria*) presents no appearance of any lobular division; it is often of very dark colour, owing to the presence of a black pigmentary matter; it consists of delicate, large, feebly-formed nucleated cells, which have no well-marked envelope, and almost appear like masses of granulo-amorphous substance; they are infiltrated with oil-drops, but present no bilious tint. There are also numerous free nuclei, and much diffused granular and oily matter as well as black pigmentary, which is in the molecular condition, and exhibits the peculiar to and fro motion. A considerable quantity of the black matter is in the form of spherical or oval corpuscles, which I described in my previous paper, and which have often a red or deep yellow tint. I supposed them at that time to be biliary concretions, but further inquiry has convinced me that such is not their nature, and that they are what I have termed them above, pigmentary formations. They are scarcely affected by the strongest reagents; liquor ammoniæ, liquor potassæ, sulphuric, nitric and muriatic acids leave them almost unaltered. On comparing them with the coloured corpuscles found in the spleen they appear quite identical, and I have little doubt are truly so; both I am inclined to think are pigmentary deposits, not necessarily derived from decomposing blood-globules. They do not occur in the kidneys, and are quite distinct from the ordinary ramifying pigment cells seen in other parts. I believe them to be a peculiar form of organic matter, rich in carbon, which not being eliminated from the blood in consequence of

the feeble grade of respiratory action, settles down as a deposit in these two parts, where accumulation of the blood and retardation of its current, one or both, frequently and almost naturally occur. In a Common Snake (*Coluber natrix*) I found the parenchyma consisting of abundant soft granulous and oily matter, with granular nuclei, faintly formed granular globules and cells; the latter were small, not numerous, and might easily have been overlooked. There were no pigmentary globules in this liver, but in one part of the parenchyma there was a deposit of bile tinging the granular matter, so that that part contrasted manifestly with the surrounding: there was also everywhere a considerable quantity of concrete solid fatty matter, sometimes of coarse crystalline aspect. The ducts in this instance were well seen ramifying on the coats of the vessels; many of them exhibited their tube of limitary membrane filled, and even apparently bulged by a soft granulous substance, which obscured the nuclei imbedded in it, and was mingled with a few minute oil-drops diffused through its mass. The most minute branches appeared to cease gradually, the basement membrane becoming at last indiscernible, and the structure then resembling a minute cylinder of granulous substance. Some of the larger ducts had more transparent contents, in which here and there small vesicles were seen.

In the Frog I have been able to examine the ducts very thoroughly; the smallest ones are I think for the most part like those in the Snake, small cylinders of granulous substance imbedding nuclei, and not usually containing vesicles; those of a somewhat larger size (but having I doubt not the same elaborating function) are usually full of pellucid contents, in which the outlines of exceedingly delicate vesicles, varying from $\frac{1}{1000}$th to $\frac{1}{3500}$th of an inch, are more or less plainly discernible. These vesicles should probably be termed cells, as on addition of nitric acid a number of nuclei are brought into view, which appear to be situate in their interior. It is remarkable how the duct tubes are filled with the vesicular and granulous epithelium; they have exactly the same appearance as their homologues in Fishes, and suggest the same ideas as to their function. In one frog the description now given exactly applied to the ducts of one lobe of the liver, while those of the other were in a very different state; instead of having pellucid contents, they presented a thick epithelial lining of rather coarse granular matter containing nuclei, and stained deeply in various parts with biliary matter. The aspect of this epithelium conveyed to the mind the idea of arrested action; it contrasted most forcibly with the delicate soft-looking granulous or pellucid epithelium of the ducts in the other part; this had the aspect of material rapidly changing into the fluid secretion, that of a stiff inert mass, whose vital changes were well nigh suspended. Connecting with this altered condition of the epithelium the manifest biliary accumulation and retardation in the ducts, the above interpretation will not appear I trust too fanciful. With the alteration in the condition of the ducts, there coexisted also a notable difference in that of the parenchyma; its cells were much more strongly formed, their nuclei and envelopes more apparent, their contents coarsely granular, and containing less oil than in the unaffected part. The

ducts were clearly seen in this instance to pursue a long course with very little ramification; one branch I traced for $\frac{1}{67}$th of an inch without observing any branch given off from it, or scarce any diminution in its diameter.

Development in Reptiles.

In Reichert's description of the development of the embryo of the Frog (von Muller's Physiology), it is stated that the anterior part of the mass of yolk contained in the cavity of the abdomen isolates itself from the rest of that substance, and becomes an independent body; which constitutes the rudimentary mass from which the liver and pancreas are subsequently formed. This I think I have also observed, or at least that as soon as the yolk mass begins to take the form of an intestinal tube a portion of it remains separate, constituting two masses, a larger and a smaller, which lie one on each side of the nascent intestine. When development had advanced a little further, and the intestine was manifestly formed, I found the parenchyma of the liver lying close in contact with it, and also a small vesicle adhering to the mass of the liver, which was certainly the rudiment of the gall-bladder. The future liver consisted of multitudes of large vesicular nuclei lying imbedded in oily matter, and the whole mass was surrounded by an investing homogeneous tunic. The gall-bladder in its earliest appearance was simply a spherical mass of similar constitution to that of the liver; subsequently it presented a distinct membranous wall lined inside by a close layer of large vesicular nuclei, the interspaces between which were occupied by oil-drops. It assumed very soon more or less of a pyriform shape, and became connected with a narrow tract stretching down to the intestine which clearly represented the cystic duct; this tract consisted of similar formative substance to that composing the liver and the gall-bladder; from it in a more advanced stage offsets were developed having the same constitution, and extending into the substance of the liver; these were beyond doubt rudimentary hepatic ducts. In one instance, where the gall-bladder existed, but was certainly not connected by a duct with the intestine, I saw lying by its side a short tract consisting of similar material, which was partially divided at its peripheral extremity; this seemed to be an early rudiment of an hepatic duct. The rudimentary ducts appeared to me to be solid tracts; I could not at this period detect a cavity in the interior; subsequently they become invested with a homogeneous tunic on their exterior, and the vesicular nuclei arrange themselves in the form of an epithelial lining, the interspaces between the nuclei being occupied with oily matter. Both in the gall-bladder and in the ducts this oily matter gradually disappears; the epithelium of the former comes to present the ordinary form of a pavement, while that of the common duct *developes cilia* which are seen in vigorous action, exciting a current downward from the liver to the intestine. I do not know exactly how long this ciliary action continues to be present in the hepatic duct; I have observed it for about a month from the date of its first appearance. As development advances the oily matter in the parenchyma of the liver diminishes, and

is replaced by granulous; pigment granules at the same time are deposited upon and in the vesicular nuclei, and thus those yellow and brown-coloured masses are formed which are so apparent in the liver of the adult animal. The gall-bladder for some time contains only a transparent fluid, which is coagulated in a marked manner by nitric acid, and is therefore probably only a solution of albumen; after a time the fluid in this receptacle has a biliary tinge, and then is not coagulated by the action of nitric acid. This was at least the case in two instances, though in another at a still later period the acid produced a precipitate which however may have been only mucus.

The general conclusions respecting the development of the liver in the Frog may be stated as follows:—

(1.) That a portion of the common formative yolk substance contained in the abdomen is set apart for the development of the liver.

(2.) That this occurs at about the same time when the intestine begins to be formed, so that the liver is not in any way derived from the intestine.

(3.) That the first rudiment of the efferent apparatus is the gall-bladder, and that the ducts are subsequently formed.

(4.) That a cystic duct is first formed, connecting the gall-bladder with the intestine, and that hepatic ducts are subsequently developed.

(5.) That these ducts are at first solid tracts, and as well as the gall-bladder primarily consist of similar formative substance to that which composes the liver.

I may add here that I have seen very distinctly the ciliary motion on the outer tegumentary surface of tadpoles as described by Dr. Gairdner; my observations were made several months before I had the pleasure of reading his description of it.

I may remark that I have obtained some very satisfactory views of the minute biliary ducts in the liver of a Rook (*Corvus*) by stripping out branches of the portal vein and washing away the parenchyma. The ducts were then seen here and there lying upon the homogeneous membrane of the vein-branches. Their condition was essentially and closely similar to that described in my former paper.

Development in Birds.

Since the publication of the account I gave in my previous paper of the development of the liver in the Chick, I have twice repeated my observations, and have found the views I advanced in the main correct. I think, however, it may be worth while to review some stages of the progress which it is important to investigate thoroughly.

The formation of the intestine takes place by the constriction of the central transparent portion of the germinal membrane; this seems to me to be a homogeneous membranous expanse, not composed of cells, and covered only with oil-drops, while the rest of the germinal membrane with which it is continuous is covered by adhe-

ring yolk-cells, and overspread with ramifications of the omphalo-meseraic vessels. When the constriction of the germinal membrane takes place, two tracts of oily matter appear, one passing forwards and the other backwards from the constricted part, where they are continuous with each other. The margins of these tracts are quite even, and soon become invested with a homogeneous membrane, but at first I doubt if this is actually present; in a chick at the seventy-seventh hour of incubation, the transparent membrane of the vitelline duct appeared to me to lose itself upon the tracts of oily matter. The upper margin of the vitelline duct and of the oily tracts forms at first nearly a straight line, which is separated by a considerable space from the vertebral column, one-half to one-third of this space being occupied by the Wolffian bodies. The posterior tract ceases near the caudal extremity; it is, I think, rather thicker but shorter than the anterior. This, in the earliest periods after passing forward with a slight curve, is lost just as it reaches a quantity of blastema situated close behind the heart. This blastema is the rudiment of the parenchyma of the liver; it does not consist of oily matter like that of the intestine, but of a less opake and more granular substance. As development advances the anterior tract continues to extend; it passes forwards and upwards above and behind the liver, and was traced on one occasion, though becoming more faint, as far as the last branchial fissure; a slight dilatation at one part of its course marks the future stomach, and from near the same part two offsets are given off, one of which runs upon the liver, the other towards the vertebral column. Both oily tracts and the offsets just mentioned are solid; they are to be regarded, I think, as a peculiar deposit of formative matter intended for the formation of particular structures; their appearance and mode of development seem to me by no means consonant with the view that the intestinal cavity is simply a part shut off from the general yolk cavity. In fact, the intestine, as has been said, is not at first a cavity but a solid tract of formative matter, and in this respect is analogous to the embryonic condition of other organs (so far as I can determine), which always seem to arise from a shapeless blastema deposited in one spot. The offset to the liver is more distinct sometimes than at others; it is most marked about the sixth day, but always may be distinguished as a small eminence of opake oily matter in the side of the intestine, until the cystic and hepatic ducts are fully formed and have united with the intestine *at that spot*. The existence of this eminence is certainly very remarkable; it may be well to give it a name and call it the *colliculus*; I do not see that its import at present can be at all explained; nor could we indeed expect this, unless we could obtain some clue to the comprehension of the mysterious principle by which the process of development is governed. I cannot see any ground for the statement that the liver is developed by the protrusion of the walls of the intestinal canal; it certainly appears at a very early period as a parenchymatous mass of blastema; and even if one could grant that this blastema originated in any way from the anterior oily tract which passes close to it, still it remains, according to my observation, perfectly unquestionable, that after the in-

testine and stomach are formed up to about the ninth or tenth day, the mass of the liver has no connection by ducts with the intestine.

In one instance I obtained a very good view of the developing hepatic duct as it approached the liver; it was formed in a tract of cell substance, which served as a blastema, and was invested on its margin by some fibrous tissue; in this the channel of the duct was excavated, which was lined by a distinct homogeneous membrane, and invested by a delicate transparent epithelium. Towards the hepatic extremity the cavity became less marked, its margin indistinct, and the homogeneous tunic less perceptible; but I satisfied myself, by very careful examination, that the duct-channel terminated by a cul-de-sac, while the blastemous tract, as yet unexcavated, stretched on much further.

In the parenchyma of the liver, just at the beginning of the fifth day, the formation of vessels and blood was very well seen; several groups of blood-globules lay in short channels provided with a fine homogeneous lining; these were oval or more elongated; they did not appear to coalesce, but were manifestly tending to such an arrangement, which a few hours later had actually occurred.

I saw no cells throwing out filamentary processes, such as Kölliker has described; the channels containing the blood-globules were spaces excavated in the blastematous mass; their homogeneous walls I believe to be produced secondarily, and their coalescence to be effected by a simple extension of their cavity.

About the eleventh day I found the parenchyma of the liver consisting of nuclei, cells, amorphous and abundant oily matter; here and there in the midst of the substance there were seen small bright yellow particles, which were doubtless biliary matter; the gall-bladder also was full of green bile, the presence of which, as there was no trace of cysto-hepatic ducts to be seen, I cannot satisfactorily explain; it does not appear to me, however, an idea to be altogether rejected, that before the hepatic ducts are fully developed, and have begun to eliminate bile in the parenchyma, their function should for a time be performed by the epithelium of the gall-bladder, which lies in close contact almost imbedded in the mass of the liver: the fact, at any rate, is, that the gall-bladder contains bile, when there is not a trace of it in the ducts, and when their development is yet incomplete.

The development of the pancreas seems to be very similar in its mode to that of the liver, and the same plan will, I believe, be found to be followed in the formation of all glands. The organ consists at first of blastematous matter, imbedding nuclei and myriads of granular globules, which are clustered over with oily molecules. The sides of the mass are even, and it presents no trace of the ultimate glandular vesicles, which are so characteristic of its adult condition. About the same time that the ducts of the liver appear, those of the pancreas begin to be developed; they are not formed by a protrusion from the intestine, but rather seem to develope themselves on the spot where they are to exist. This at least is the case with the main trunks; the smaller branches are no doubt formed by an extension of the cavities of the larger ones.

It must be sufficiently apparent how essentially similar the development of the liver and its apparatus of efferent ducts is found to be in the three lower vertebrate classes. Hitherto I have not been able to pursue the examination in Mammalia; and though I am aware that Bischoff's account of it in this class is in accordance with the view of its being a protrusion from the intestine, yet I must remark that the process, as being conducted more slowly in the lower classes, is more favourable for correct observation, and that it seems unlike the known unity of scheme which characterizes the works of Nature, to find an essential difference in one class from that which prevails in the three others.

I have little to add to the anatomical account I previously gave of the condition of the liver in Mammalia; I have studied it recently more particularly with a view to the elucidation of its function, and will now only touch on those points which bear upon this matter. One most important question to determine positively is where the bile is in the healthy state necessarily formed; whether in the cells of the parenchyma, or in the ultimate hepatic ducts. The prevalent opinion among physiologists certainly is that the bile is actually and necessarily formed in the hepatic cells; they are considered homologous to those of the renal tubuli, and on account of this homology and a certain not very manifest yellowish tint, it is usually held that the bile is primarily formed in them, and liberated by their dehiscence in the cavity of the duct. From this opinion, which I long held unquestioningly, and to which I have often referred, observation alone inclines me in some measure to dissent. I have scrutinized numerous specimens of the livers of our ordinary domestic animals with a view to determine this point, and still cannot convince myself that bile is present in the parenchymal cells as *a normal* and *necessary* condition. If present, it ought not to be very difficult of detection, seeing that it is a coloured fluid, and that the cell which contains it is in this class generally provided with a distinct envelope: it ought, in fact, to be as apparent, or nearly so, as it is in the cells of the follicular livers of Mollusca. But this is not the case; according to my observation the cells commonly appear as pale granulous nucleated particles, with a more or less distinct limiting envelope, and presenting a few or perhaps numerous and large oil-drops amid the soft albuminous mass. Not unfrequently a distinct yellow fluid is seen infiltrating the granulous contents, or several yellow highly refracting drops are observed in the same situation; this indicates of course that bile is present in such particles, but they are seldom seen except when the liver is in a state of so-called biliary congestion. This condition is consequently most often observed in human livers. The cells, when massed together and viewed by transmitted light, very commonly, perhaps always, produce a kind of reddish yellow tint; but this seems to me to differ decidedly from the yellow tint of bile, and to be probably dependent on some diffused hematin tinging the cells, or on some modification which the light has undergone by unequal refraction in its passage through the mass; at any rate I could not, were I advocating the opposite opinion, rely on it for a moment as sufficient evidence of the presence of

bile in the cells. In some instances of healthy livers in animals, as in the Mole (*Talpa europæa*), the Hare (*Lepus timidus*), and the Squirrel (*Sciurus*), and also in others, I have noted the presence of biliary matter in the cells; nor do I doubt in the least the possibility of its being frequently so found, only it seems to me that evidence is wanting to show that this condition is constant and essential. I have often tried the effect of adding nitric acid to the cells, but I do not think that I have thereby obtained any more decisive evidence regarding the point in question; this reagent makes the cells more opake, contracts them, renders their envelopes more marked, and their contents more granular, but does not impart a more positive biliary tint. I think as soon as a real yellow tint exists the eye will judge of it much more satisfactorily when the cells are in their natural state, than when they are shrunk and entangled amid granular films of coagulated plasma.

Not wishing to rely solely on my own observations, I wrote to three of the most eminent physiologists in London, requesting they would inform me of their views on the matter; they kindly replied to my inquiries, and permit me to subjoin their replies. Mr. Bowman's communication is as follows:—"My notion of the matter you refer to is shortly this, that the bile does exist in those hepatic cells that lie nearest to the surface of the lobules, *i. e.* to the portal surface where the ducts commence; not that those cells contain nothing but bile, but that bile comes out of them, either by their rupture and deliquescence, or while they lie *in situ*, undergoing only such slow degeneration as is common to the elements of most or all tissues. That the cells lie in series extending from the hepatic venous to the portal venous surface, and that there is an onward march of the cells from the former to the latter; those near the former being immature, and those near the latter mature; that the bile is gradually elaborated by the agency of all, but probably chiefly by those situated nearest the portal surface. The yellow and brown hepatic substances are the immature and mature hepatic cells respectively. The congestions of Kiernan seem to me to depend on the bulk of these cells respectively, allowing the capillaries which flow through them to hold more or less blood after death. Many of the morbid appearances of the liver are, in my opinion, dependent on diseased conditions of one end of the series of the hepatic cells (the hepatic venous or the portal), to the exclusion of, or in a different way or degree than that other." This view of Mr. Bowman's is nearly the same as that I proposed in my first paper on the Secretory Apparatus of the Liver, published in the Philosophical Transactions; only that I believed the cells not to progress ("march") outwards from the centre, but that the bile was transmitted from cell to cell in order throughout a series. What led me especially to doubt of the truth of this opinion, was simply that in the majority of livers I saw oil only, and not bile in the cells. If oil be regarded as the secretion of the hepatic cells instead of bile, the view of Mr. Bowman would receive very strong support, for oil does accumulate in many instances, especially in Sheep's and in certain Human

livers*, in a very remarkable manner in the marginal cells of the lobules, so as to form a complete opake border to them; and these same oil-laden cells are seen at times dehiscing, and apparently discharging their contents into the fissure.

But oil is not bile, and therefore this very case becomes an objection to the view of Mr. Bowman; for if bile is perfected in the marginal cells, it ought to be manifest and preponderating there, which in these instances, and indeed generally, is not, as far as I have seen, the case. Another condition, which I have several times observed in Human livers not seriously diseased, also appears to speak counter to the view of bile being perfected in the marginal cells of the lobules. In these, for instance, when a transverse section had been made, the central part of the lobules was seen of a distinct yellow tint, the cells manifestly containing bile; this colour shaded off towards the margin, and ceased some distance from thence, while the marginal cells themselves, for a depth of two or three in the central direction, were the seat of considerable *oily* accumulation. This could hardly have occurred if the perfection of bile by the marginal cells were a necessary step in the process†.

Though not at all essential, though I believe the ducts often form bile when none exists in the marginal cells, still there does appear to be a peculiar tendency in the cells in this situation to fill themselves with biliary matter. I have seen bile in the marginal zone of cells when all the rest of the lobules was in a state of complete degeneration; I have observed in the liver of an animal, to whom calomel had been given, bile, though present elsewhere, yet most abundant on the margins of the lobules; I have seen a similar state, accumulation of bile in the marginal cells, occasionally in Human livers; and lastly, I have often found biliary deposits adhering to the ducts in the oily livers of fish, occupying thus an analogous situation to that of the bile in the preceding instances.

The circumstance that oil in many cases accumulates particularly in the marginal zone of cells, seems to me most probably accounted for by the relation of this part to the circulating blood. These marginal cells are, in fact, the first which are exposed to the stream of portal blood as it enters the lobular capillary plexus; they consequently obtain most abundantly the oily matter therein contained, and store it up in their cavities; this, I think, is a more probable view, according to our present knowledge of the habits of cells, than to suppose that the oil is transmitted from the

* *Vide* Report of the Pathological Society, 1846, 1847, p. 105.

† When a liver presents the "nutmeg appearance" in the most marked manner, the following is commonly found to be the condition of the structure. There is fatty degeneration of the marginal zone of the lobules, which is thereby rendered quite pale; while the central part, occupying perhaps rather more than a half, is uniformly saturated by a deep venous congestion. The cells in this part are in great measure destroyed, reduced to a granular detritus, and the remaining ones are converted into spherical masses of orange pigment. The sanguine congestion and the pigmentary accumulation are precisely coterminous. Now unless the ducts themselves are the effective agents, how can such a structure secrete bile? How is the central yellow pigment to be conveyed through the marginal zone of fatty degeneration?

central cells in the direction outward. How to account for the occasional presence of bile sometimes in the central, sometimes in the marginal cells, I do not know; but the variability of its seat, as well as its frequent absence, testify, I think, against the view of the secretion of bile being an *essential* part of the function of the hepatic cells. I may remark that the seat of oily accumulation varies also as that of biliary; in the livers of Dogs I have often found it in the central parts of the lobules around the intralobular vein; this is, I think, less common than the other, and I can offer no explanation of it.

Mr. Simon states to me, "that in perfectly normal conditions among vertebrate animals, bile, to the best of my belief, *cannot* be demonstrated to exist in the hepatic cells, and I have for a long while strongly inclined to the belief that normally it never lies within them."

Professor Paget's testimony is to the same effect: "I quite agree with you that in the healthy livers of men the cells do not contain any coloured material, but I think I have seen their contents partially coloured yellow in other cases than those of congestion."

My belief therefore is, that *in perfectly healthy states* of the mammalian liver bile does not exist in its cells, that it is not in any case *necessarily formed* there, but that this may be always effected by the ducts. It remains then to inquire what circumstances produce biliary impletion of the cells, so that they manifestly contain bile. Congestion of the portal-hepatic capillary plexus with blood, and this chiefly of a passive kind, I am inclined to regard as one principal cause. I have frequently observed in cases of heart-disease impeding the onward current of the blood, that the cells of the liver, especially those in the centres of the lobules, were gorged with bile. It is in the central part that congestion of blood is most frequently manifest; here it commences as hepatic venous congestion of the first degree, and from hence it extends outwards towards the interlobular veins. This seems to indicate that a connection obtains between passive congestion of the blood-vessels and biliary impletion of the cells. Another, and probably not less frequent cause, especially of the slighter states, is the cessation, more or less complete, of the excretory action of the ultimate ducts, the spasm of the gall-ducts of former authors; when this occurs, the biliary matter, not being eliminated from the blood by the ultimate ducts, is carried on in the blood current, and deposited in the parenchymal cells, thus producing jaundice of the liver, which, as Virchow remarks, must precede jaundice of the body when this is of hepatic origin. Biliary matter may also collect in the cells no doubt, when a larger quantity of it than natural is present in the mass of circulating blood, whether this depend on insufficient oxygenation in consequence of a sedentary life and rich feeding, or on certain atmospheric influences; in this case the excess which the excretory ducts are unable to carry off passes on, and is deposited in the parenchyma. I think that the accumulation of a large amount of oil in the hepatic cells does not generally coincide with the existence of bile in them, and *vice versâ*; thus in the fatty liver of phthisis

and of fish there is scarce any trace of bile to be discerned, while in the follicular liver of Mollusca the dark biliary matter very greatly preponderates over the oily; sometimes, as has been mentioned, we see different parts of the lobules the seat of oil and bile respectively; and this is most usually the case, though there is no doubt that the two products may coexist in the same cell*.

The exact relation which the smaller and terminal ducts bear to the parenchyma is the present "vexata quæstio," and any observations that tend to elucidate this matter, and render it more easily determined, are worth our attention. I have made many examinations since the publication of my last paper relative to this point, and have been by them decidedly confirmed in the views there expressed. I stated that I believed the ducts did not ramify extensively, did not extend far beyond the "spaces," and that many fissures seemed quite destitute of them. This is, I think, generally the case, but in some instances the ducts seem to extend farther than others; with regard, however, to the main point, that the cells are a *parenchyma*, and not an *epithelium*, I entertain no doubt whatever. In many, if not in all London dogs, and in some rabbits, there is found a peculiar condition of the epithelium of the whole excretory apparatus of the liver, which renders it comparatively easy to trace and follow the ducts to their terminations. If thin sections be made of such livers, the ducts are seen as opake tubes or tracts, appearing whitish by direct light, which come up from below at the "spaces," where three lobules adjoin, divide irregularly, and run for a varying distance along the fissures. These tubes run often a long distance without branching; they are most often single, one only traversing each portal canal or fissure, and what is especially remarkable, not maintaining any close relation to the wall of parenchyma, between which and them a distinct interval is often to be seen.

Their mode of termination varies; sometimes they break up into a few delicate branches, which may give the appearance of a plexus; sometimes they terminate by apparently losing themselves, that is to say, they gradually cease, their structure being indiscernible beyond a certain point, or breaking up into a mere streak of oily molecules. Generally I think the ducts, as seen in these specimens, are confined to the canals and fissures, but minute branches are often seen which just enter their substance for a little way: I have never observed anything that in the least indicated that the ducts formed a plexus containing the cells in anastomosing tubes as described by Dr. Leidy. The opacity which renders the excretory ducts thus unusually distinct, is occasioned by a deposit of minute oil-molecules between the nuclei which intercept the light; this oily matter replacing in part the ordinary granular basis substance, and representing the oily matter which occurs so abundantly in the cortical renal tubuli of all London cats.

* I request the reader to bear in mind that Mr. Lindsay Blyth's experiments subjoined to this paper have fully shown that yellow pigment in the cells is not, at least commonly, any proof of the presence of true bile. The above was written before his experiments were performed.

It is perfectly clear that in neither of these cases it interferes in the least with the healthy discharge of the function, and we may learn therefore that excess alone of oil in any part does not constitute "fatty degeneration." The epithelial particles of the gall-bladder in these cases are loaded with oily molecules; they easily break up, and give exit to it very soon after death. No such oily accumulation occurs, at least necessarily, in the parenchymal cells; a further confirmation of the opinion above stated, that these cells are not, *quoad* position, a continuation of the epithelium of the ducts.

In some Human livers I have recently observed the ultimate ducts in a very satisfactory manner, and believe, on the whole, that the mode I am about to mention is the best for obtaining a view of their course and relations. A very thin section of the liver must be made at one or two lines depth from the surface; this is to be treated with acetic acid, and moderately compressed; if the liver be tolerably free from oily matter it will now become much more transparent, and on careful examination of the portal canals, spaces and fissures, some ducts will be found, and their course may be traced. It is manifest that in this way of proceeding the ducts are examined *in situ*; and if the observer have previously acquainted himself with their appearance by dissecting them out as they lie in the Glissonian sheaths, he will have no difficulty in recognizing them and following them, though he may have much difficulty in convincing himself of their actual mode of termination. Their termination by distinctly closed extremities I have certainly observed, as well as the slight amount of ramification they present, and the little intimate relation they appear to hold to the walls of parenchyma between which they run. In many fissures not a trace of them can be seen; and in those where they exist it is manifestly impossible that they can come into relation with any more than a very small portion of the parenchyma. How then, if all the cells secrete bile, could this make its way into the ducts? The ducts as they run in the fissures and canals are in the closest relation to the portal vein branch, and surrounded by the terminal plexus of the hepatic artery; so delicate, so truly homogeneous is the tunic of the vein, that it seems to me scarce possible but that the ducts in the smallest portal canal and fissures should be bathed in plasma exuding from it; from the plexus of slender capillaries, in which the hepatic arterioles terminate, they must also receive part of their supply; and lastly, when the secretion of the marginal cells of the lobules is abundant, or when the liver, as in fish, is a mass of oil, they must be bathed in this fluid.

In considering what is probably the function of the parenchyma, *i. e.* of the chief mass of the liver, we may with advantage enumerate *seriatim*, the chief points which may be regarded as pretty well ascertained respecting it. (1.) It consists, at least in Mammalia, of cells, which as long as they retain their active power exhibit nuclei; these nuclei are imbedded in a soft homogeneous granulous substance which very commonly contains oil-drops, and sometimes biliary molecules, or is tinted with bilious fluid; an envelope much more distinct than in most other glandular cells surrounds the whole particle, and seems to denote a certain amount of permanency

in its structure. (2.) These cells are very often arranged in tolerably perfect rows radiating from the centres of the lobules, but this disposition is often exchanged for a plexiform or quite irregular one. (3.) The marginal cells of the lobules, *i. e.* the ends of the rows, are especially prone to be the seat of oily accumulation. (4.) There is no arrangement of the cells comparable to those of the renal tubuli; they form rows, but not in any way the parietes of a tubular passage. (5.) There is no basement membrane to be seen in the lobules, the cells therefore lie in the closest relation to the blood in the capillaries. (6.) Young cells are frequently seen forming in the parenchyma, by collection of granulous matter round free nuclei; these do not seem to form at any particular part more than at another; they are not found solely in the centres of the lobules, *i. e.* at the commencements of the series. (7.) The cells* have in many animals a great affinity for oil, and appropriate it so as to gorge themselves when it exists in any quantity in the blood. (8.) Sugar must doubtless also exist in the cells, as they constitute a far greater part of the parenchyma than the diffused granulous plasma; according to some observations I have made its amount is in inverse ratio to that of the oil present, for in fatty livers of fœtal animals, fish, and diseased persons, I have failed to detect by TROMMER's test the presence of sugar, which in healthy ones is always abundantly manifest. (9.) Bile, or at least the colouring principle of bile, often occurs in the cells, especially in various diseased conditions, but is not proved to exist in perfectly normal states. It thus appears that the hepatic cells differ in several particulars from the cells of other glands; they are more perfectly formed, of more permanent aspect; they are not disposed as a lining to tubes of homogeneous membrane, but in series which tend more or less to plexiformity, and are apparently distant from any free surface open to the exterior. I consider them, therefore, to form a *parenchyma* and not an *epithelium*. Their peculiarly intimate relation to the blood capillaries seems to indicate, as I suggested in my former paper, that they serve as repositories for certain matters absorbed by the blood from the chyme as it passes over the intestinal surface; these matters are however, doubtless, altered by the recipient cells and converted into sugar, perhaps also into oil or biliary matter.

It is clearly proved that sugar is *made* in the liver, that it is not found in the blood entering the liver by the vena porta, but that it exists in very large quantity in the blood passing out by the hepatic vein; the substance also of the liver, the parenchyma, contains abundance of sugar, as I have repeatedly observed. These facts show that one, and probably the chief function, of the hepatic cells is to elaborate sugar from the materials intended to be employed in respiration; and that having done so, they allow this product to return into the circulating fluid, where it perhaps undergoes further changes before it terminates in carbonic acid. The parenchyma of the liver thus resembles closely a ductless gland, such as the suprarenal capsule, allowing its

* To this the liver of a fatted pig presents a remarkable exception; its cells seem inapt to receive the oil which so accumulates in the subcutaneous tissue.

product, like it, to return to the blood from which it had been elaborated: it may also be inferred, as not improbable, that as the elaboration of sugar is certainly one purpose fulfilled by it, so it is more likely that the bile-secreting function properly belongs to another apparatus associated with it, that of the excretory biliary ducts.

Some evidence as to this question which I have sought to obtain from chemical investigation, on the whole corroborates, I think, the view above expressed. I made an alcoholic extract of portions of the liver of several animals, evaporated this on the water-bath to dryness, and employed PETTENKOFER'S test for bile. I obtained no decisive characteristic reaction, such as is described to ensue if bile or its constituents are present; a very feeble crimson tint was developed in most cases at the moment of adding the sulphuric acid, but it very quickly disappeared, and was so faint during the brief time it lasted that I cannot think it proves the presence of biliary matter; moreover, as it is quite impossible to obtain the parenchyma quite free from the minute ducts, some of them may have imparted a slight admixture of bile which was not derived from the parenchyma; or, which is perhaps unavoidable, some oleic acid may have been dissolved by the menstruum, and given, as it is said to do, a similar reaction with PETTENKOFER'S test as bile itself. Before I was aware that albuminous matter produced with sugar and sulphuric acid the same reaction as bile, I conceived that I had found certain proof of the presence of biliary matter in the cells by applying this test to a thin slice of liver and watching the changes under the microscope; under the action of the acid the tissue became much more translucent, and developed along its margin a beautiful permanent crimson tint. The very same however, even more intense, was produced by treating a section of kidney in a similar way, so that it was manifest the reaction depended on nothing special to the liver.

One other fact we may receive from chemistry, which is also corroborative of the view that the sugar and bile are not produced in the same parts, viz. that the bile does not contain the hepatic sugar. M. BERNARD distinctly states this, and on repeating the experiment I obtained the same result. Sugar therefore seems to be the normal product of the cells, bile of the ultimate biliary ducts.

Mr. NOAD has been kind enough to execute some analyses for me, which go to show that the kind of food influences decidedly the amount of sugar contained or formed in the liver. The subject of the first was a young dog, who was fed for six days on bread and meat; the quantity of sugar contained in his liver, as determined by fermentation, was 20·13 grs. per 1000. The second, a young kitten, was fed for six days on food as far as possible of the saccharine kind, rice, sugar, arrow-root and potatoes; this disordered her bowels after some days, but by leaving off the rice and confining her to potatoes chiefly she recovered her health. Her liver contained 31·66 grs. of sugar per 1000; it also was seen under the microscope to contain much oil. Another kitten of the same age was fed for about a week on bread and butter, and milk, so as to approach nearly to a diet of oily food; her liver was quite opake from the presence of abundance of oil, much more manifestly being present than in the two others; it yielded by fermentation 21·13 grs. of sugar per 1000.

The results stand thus:—

Albuminous food per 1000 grs. of liver	20·13 grs. of sugar.
Saccharine food per 1000 grs. of liver	31·66 grs. of sugar.
Oily food per 1000 grs. of liver	21·13 grs. of sugar.

Hence the saccharine diet produced fully one-third more sugar than the albuminous or oily. M. Bernard however has distinctly proved that the liver forms sugar from the blood when only albuminous food is taken, so that it seems certain that a converting change must go on in the organ, which is exerted not only upon saccharine, but also upon albuminous and probably upon oily matters. One of the results of this converting change may sometimes be biliary matter, which would then appear in the cells, as we have seen that it occasionally does; but in the majority of cases observation seems to testify that sugar and oil are the products or results of the energy of the hepatic cells.

I would for a moment refer again to a point noticed in my previous paper, viz. *that at the moment when the liver traced in the ascending animal series assumes a solid parenchymal form, it receives a portal vein which is distributed exclusively to the parenchyma*: this at once seems to imply a special relation between the two, that the one is developed for the sake of the other, and that their functions are coordinate. A portal vein is not needed for the secretion of bile; this product is most copiously formed in the follicular livers of Mollusca, which are supplied by an hepatic artery only; and it therefore is extremely probable that the parenchyma is added for some further and different purpose; this purpose being, as I have suggested, the temporary abstraction from the blood of such matters as being absorbed in considerable quantity from the intestinal surface could not, without disturbing too far the due crasis of the blood, be immediately poured into it. It is impossible to conceive a structure better fitted to fulfil this purpose than the lobules of the liver, which are percolated from their circumference to their centre by capillary blood streams.

The function of the parenchyma I believe, then, to consist chiefly in exerting a modifying action on the portal blood and preparing a product which enters the circulation, and is probably consumed in the service of respiration. The presence of much oil in the cells seems chiefly to depend on the existence of an unusual amount in the blood, which may be occasioned by various causes; thus the fatty liver of fish and of the fœtus seems connected with a low degree of respiration; that of phthisis partly with increased absorption of fat, partly with diminished respiration; that of sheep fed on oil-cake with the oily nature of the food. To three of these cases certainly, if not to all, the term fatty degeneration is quite inapplicable; the condition is that simply of oily accumulation.

The function of the excretory ducts, if my description of their relations is correct, is not merely that of conveying forth out of the organ a product already formed; they must act upon certain matters supplied to them with an energy of their own, and out of these elaborate their secretion themselves. It may be said generally that

the ducts which present the structural characters that appear indicative of an active function, *i. e.* those which approach their termination, are in contact with parenchymal cells and celloid particles containing varying quantities of sugar, albumen and oil; they are also surrounded by the rather scanty plexus of the terminal twigs of the hepatic artery, and moreover they run in such close relation with the delicate walled portal vein branches that they may possibly receive plasma exuded from them. In fishes' livers, where the quantity of fibrous tissue is small, it is very remarkable to observe how the ducts are encrusted with the oily parenchyma, as it were bathed in its fluid; in this instance it is impossible to avoid the idea that this abundant oil serves to the ducts as a plasma, *out of which*, by means of their epithelium, they elaborate bile. The same must hold in cases of fatty liver in higher animals; and generally it seems probable that the parenchyma furnishes a suitable fluid (which may often be in part already of biliary nature) which the ultimate ducts employ in their eliminative action.

Now have we any evidence tending to show that an active change is taking place in the ultimate ducts,—that they are more than mere efferent channels? Such I think has been already detailed, and I will refer to it here again.

The presence of abundant granulous matter in the ultimate ducts of fishes' livers speaks in favour of an active change proceeding in these parts, as also do the pellucid vesicles, which often crowd together so closely in them; such surely would not be found in a mere efferent canal. Compare the condition of the epithelium of the cortical renal tubuli of those in the medullary cones as an illustrative instance; in the first, the nuclei, surrounded with abundant granulous matter, constitute celloid particles and sometimes cells; in the other, the nuclei lie applied against the limitary wall almost naked and alone. Manifestly the one is a secreting part, the other a mere channel of exit. In Reptiles and Birds the case is the same; the ultimate ducts are not lined by small epithelial particles, but well nigh filled with vesicles or granulous matter, which must be supposed to be continually breaking up into the fluid secretion and some complementary matter. In Mammalia we meet ordinarily with a seemingly different condition of the ultimate ducts, which, though rare, also occurs in Fishes and Reptiles. The nuclei are not buried in granulous matter, but are set as it were in a thin layer of it, and leave a distinct central channel between the opposite walls; yet they are not formed into distinct particles; there are no columnar cells like those of the larger ducts; the nuclei abide in all their separate entireness. Have we knowledge of any secretory structure similar to this, with which we may compare it, and which may aid us to comprehend it better? Such a one is found in the cavities of the thyroid, where the epithelial layer, precisely similar in constitution to the walls of the ultimate biliary ducts, rests externally upon the limitary membrane, and internally is in contact with the secretion it has elaborated. Can we interpret the import of this arrangement? Can we perceive its peculiar significance? It seems scarcely doubtful that the more perfect a cell is the greater is its permanence; a

celloid particle may rapidly decay, but a cell with a well-marked envelope is destined to a longer life; its contents are as it were locked up. In such cells too, when the secretory act is ended, the nucleus disappears, and the cell is henceforth only a repository of the product. This type of secretory action is, compared to the other, gradual and slow. But if a nucleus remain as such, if it exert an unceasing energy, or at least retain the power to exert that energy at intervals, if instead of developing a single cell, filling it with secretion, and then perishing, it continue to attract, to change and to repel charged matter, then we have a structure which is adapted for continuous, and, it may be, rapid action. This we have much reason to believe is the case in the instances of the thyroid and of the biliary ducts.

I might also refer to the case of the intestinal villi during absorption, which is a rapid and temporary process; the nuclei seem to attract the chyle into the villus; they do not develop cells wherein to enclose it, but allow it straightway to flow off by the lacteals, while themselves unchanged continue to attract fresh matter.

I believe then the two conditions of the ultimate ducts to be essentially similar, differing only in the more or less quantity of granulous matter, by whose disintegration in each case the material of the secretion is furnished; the presence of the vesicles in the ducts so often mentioned, seems to me strongly indicative of active growth, though less rapid, and by consequence of change and decay; and thus corroborates decidedly the view I have expressed.

Once I have seen the nuclei of the ultimate ducts deeply bile-tinged; this was in the liver of a Squirrel (*Sciurus*), where many of the parenchymal cells also contained bile; this also seems to indicate an attractive power resident in them; it was remarkable that some ducts were not thus coloured, and in these the nuclei were less elongated, were plumper, more healthy and vigorous-looking, to use a metaphorical expression. The gall-bladder was nearly empty, and the condition, I suppose, was one of sluggish action of the ducts; hence impletion of some of the parenchymal cells with bile, and staining of the nuclei of the ducts with secretion not thrown off. Those unstained were doubtless efficient and active.

As it appeared to be matter of great importance to ascertain whether the parenchyma of the liver really contained bile, that is, not only the colouring matter of the secretion, but its organic salts also, I applied to my friend Mr. Lindsey Blyth, who most kindly undertook at my suggestion a series of experiments to endeavour to decide the question. I may remark, that in the case of the liver there is far more reason to expect that its secretion should be capable of being detected in its substance, than there is in that of the kidney; urea cannot be found in the renal parenchyma, probably because it is so rapidly and completely carried out of the tubes of which it consists, and which present only an extremely thin layer of epithelium to be traversed in its transit from the blood into their cavity. But in the liver, the bile, if it exist

in the cells, has no ready means of escape; it must traverse a long series before it can be received into the ducts, and those who affirm that it exists in the cells, point to the yellow matter contained visibly in their interior as proof of its presence. It is to be supposed therefore that if this yellow matter be bile it will give the characteristic reaction of this fluid.

Experiments.

(1.) Healthy Sheep's liver weighing 2 lbs. Separated the mass of the parenchyma as much as possible from the larger vessels, made a watery extract from which the albumen was separated. TROMMER's test showed the presence of sugar in abundance; PETTENKOFER's gave no indications of bile; evaporatedt he extract to perfect dryness, and then treated it with cold absolute alcohol, and then with boiling spirit, neither of which gave any indications of bile. The solutions tested were very concentrated; the whole extract obtained from the mass of 2 lbs. weight was contained in about 1 oz. of fluid.

(2.) A portion of a Pig's liver, treated in a similar manner. Abundance of sugar was obtained, no trace of bile.

(3.) A healthy Human liver, weight 2 lbs.; the whole parenchyma was treated in the same way as that in experiment (1). The watery extract gave abundance of sugar, no bile. The cold alcoholic solution precipitated by ether gave no indication of the presence of a salt of cholic acid.

(4.) A small piece of Human liver. The cells engorged with yellow matter; first treated with alcohol, which on testing gave no trace of bile, but took up a beautiful deep yellow pigment and oily matter. The watery extract gave no trace either of bile or sugar, but the addition of sulphate of copper and liquor potassæ produced a beautiful azure solution, from which nothing was precipitable by heat.

The addition of a very minute portion of bile to the alcoholic solutions caused the characteristic reaction to take place with PETTENKOFER's test.

(5.) A Human liver; the subject a strong healthy man, who died from a fracture of the thigh; it presented a healthy appearance. No trace of sugar or bile was found in it. The patient had partaken of no food for two days previous to death, excepting a small quantity of beef-tea from time to time.

(6.) A portion of Human liver, of decided yellow tint, the cells generally gorged with oil, some containing yellow matter. The man died from the shock of an accident, which caused fracture of the pelvis. The ethereal extract gave a liquid oily product, on which nitric acid produced a play of colours, but no trace of cholic acid was found by PETTENKOFER's test. The alcoholic extract gave a solid fat, but not of so deep a colour as the ethereal, and a very slight reaction with nitric acid. No trace of cholic acid was found in it. The watery extract gave no trace of sugar or bile. Potash and copper being added gave a dirty brown solution, from which nothing was thrown down by heat or was deposited after standing.

(7.) A piece of Human liver of healthy appearance, but the cells around the intralobular veins contain a great deal of deep reddish yellow matter. Four extracts were made. 1st. Chloroform gave a beautiful crystalline residue of solid fat, partly coloured with yellow spots. PETTENKOFER's test gave no trace of cholic acid; nitric acid gave a very slight purple tinge, which changed into green. 2nd. Ether gave an abundant deposit of oils and fats which produced a slight reaction with nitric acid, but no trace of cholic acid with sugar and sulphuric acid. 3rd. Alcohol gave a coloured extract containing fatty matters, more solid than those from ether, but showing on being tested no trace of cholic acid. 4th. Water; the extract gave no trace of cholic acid, but on the addition of liquor potassæ and sulphate of copper, a portion of the copper was reduced by boiling to the red oxide, and the supernatant liquor remained of a beautiful azure tint, in which no change was effected by heat on long standing. This azure colour, as in (4), probably indicates the presence of glycocol, which is united with cholic to form the glycocholic acid of the bile. The fatty matter saponified by potash and extracted with alcohol gave no trace of cholic acid.

(8.) A cat's liver; the animal had been treated with calomel, and had taken twelve grains in twenty hours. The aqueous extract gave some trace of sugar and of fat, but none of cholic acid.

(9.) Liver of a man who died with suppuration in all the divisions of the portal vein, the smaller branches being blocked up. The interior cells of the lobules were filled with yellow matter. The aqueous solution of the parenchyma gave no indication of cholic acid or sugar, but with TROMMER's test a solution of fine blue colour was obtained, from which nothing fell down on boiling or after long standing. This seems to indicate the presence of glycocol. The gall-bladder was inflamed; its contents gave no reaction of cholic acid or sugar.

(10.) Liver of a female extremely fat; died with tubercular cavities in lungs. The presence of sugar and probably of glycocol was ascertained by TROMMER's test. The contents of the gall-bladder were thick and of a dark saffron colour; contained very little cholic acid, no sugar, a great deal of colouring matter.

(11.) Liver of a patient who died from inanition ten days after having cut his throat; it gave no trace of sugar nor of glycocol.

(12.) Liver of a distinct yellow colour, extremely fatty, the cells gorged with oil, and containing much yellow matter also. The aqueous solution gave a deposit of suboxide of copper with TROMMER's test, and the supernatant liquor remained of a purple colour, thus indicating the presence of sugar and glycine. The alcoholic solution gave a beautiful reaction with nitric acid (first green and then purple), characteristic of the colouring matter of the bile, but no trace of cholic acid; it contained also a small quantity of fatty matter. The female from whom this liver was taken, was jaundiced at the time of her death.

The conclusions which may be drawn from the foregoing observations are—

(1.) That sugar, bile-pigment, and probably glycocol, can be detected in the hepatic cells. (2.) That cholic acid cannot be detected in them, and that therefore it is not necessarily united with the bile-pigment. (3.) That after abstinence from food sugar disappears from the liver. If these conclusions be admitted, it is clear that the hepatic cells do not form perfect bile; they form sugar, and two of the biliary principles, but not the organic acid, which is probably the most important.

Explanation of the Plate.

PLATE I.

Fig. 1. Ducts containing vesicles imbedded in pellucid and amorphous matter; they are such as I believe to have an *active* function. Diameter $=\frac{1}{1000}$th of an inch.

Fig. 2. Gall-bladder, cystic, hepatic and common ducts in a very young fish, together with the intestine: the hepatic ducts appear as rudimentary developments from the cystic.

Fig. 3. (*a*) An ultimate duct, with closed extremity, consisting of nuclei set in a sub-granular basis substance from liver of Frog.

(*b*) (*b*) Two ducts containing the vesicular epithelium from a different part of same liver. The diameter of these two was, that of the larger $\frac{1}{714}$th of an inch, that of the smaller $\frac{1}{833}$rd of an inch. The duct (*a*) had a diameter of $\frac{1}{1250}$th of an inch.

(*c*) Duct from a young rabbit, dosed with blue pill; it contains very numerous delicate vesicles with interposed oily molecules. Its diameter $=\frac{1}{1000}$th of an inch, that of the vesicles $=\frac{1}{3500}$th of an inch.

Fig. 4. Alimentary canal and liver of Tadpole, with gall-bladder and rudiment of duct. *s*, indicates the stomach; *t*, the throat; *i*, the commencement of the intestine; *l l*, the two lobes of the liver; *g*, the gall-bladder, lined by a vesicular epithelium; *d*, the rudiment of the cystic duct. The liver consists of mere formative yolk matter; the duct seemed to consist of similar substance but more opake; it was not hollow; its margin was very defined. The gall-bladder measured $\frac{1}{65}$rd of an inch in diameter; its cavity was filled by a clear fluid.

Fig. 5. (A.) A terminal duct from the liver of a Guinea Pig; it had a most distinct closed extremity; its diameter $=\frac{1}{1000}$th of an inch, that of its canal $=\frac{1}{4000}$th of an inch. It was seen lying along the wall of a tolerably sized portal canal. Some of the parenchymal cells are represented.

(B.) Ducts from Squirrel's liver; one is seen lying on the homogeneous tunic of a blood-vessel (a portal vein branch); its extremity was even, and was probably terminal; its nuclei were bile-tinged. The other duct has very

distinct nuclei, which appear plump, and are not bile-tinged; its amorphous substance also is paler. A parenchymal cell, about $\frac{1}{1000}$th of an inch in diameter, is figured. The two ducts had each a diameter of $\frac{1}{3500}$th of an inch.

Fig. 6. View of a portal canal and portions of the two parietal lobules, with an ultimate duct running in the space nearer one side than the other. The duct is single; no other existed in this part; it gave off no branches, and had no communication (visible at least) with the lobules. The diameter of the portal canal was $\frac{1}{333}$rd of an inch, that of the duct $\frac{1}{1100}$th of an inch. The specimen was taken from a dog, in whom the epithelium of the gall-bladder and the ducts was in the oily condition described in the text. The larger ducts had a distinct homogeneous tunic, the smaller no perceptible one, but consisted of groups of minute oily molecules, which formed at last mere streaks; a distinct closed rounded extremity was not observed.

Fig. 7. View of one of the glands of the large hepatic duct-trunks in the liver of a Dog; it belongs to the conglomerate type: its cavities were *filled* with an opake granulous matter containing numerous oil-drops, as well as many nuclei. Some of the contents are figured on the side.

II. *On the Morphology of the Cephalous Mollusca, as illustrated by the Anatomy of certain Heteropoda and Pteropoda collected during the Voyage of H.M.S. "Rattlesnake" in 1846–50.*

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Received March 18,—Read May 13 and 27, 1852.

"THE mere description of appearances even of the interior structure, still less of the exterior surface of an animal, without the deductions which they legitimately yield, is of comparatively small value to the philosophic naturalist; for of what value are facts until they have been made subservient to establishing general conclusions and laws of correlation, by which the judgment may be safely guided in regard to future glimpses at new phenomena in nature*?"

If I prefix this admirable exposition of the true aims of anatomical investigation to the present essay, it is that I may justify, by the highest authority, the course which I have taken in considering what of new facts it contains, as of subordinate importance to the reasonings which may be based upon those facts; in making its scope more morphological than zoological.

The morphology of the Cephalous Mollusca is a subject which has been greatly neglected. No Savigny has determined the homologies of their different organs, and so furnished the only scientific basis for anatomical and zoological nomenclature.

It is not settled whether the back of a cuttle-fish answers to the dorsal or to the ventral surface of a Gasteropod. It is not decided whether the arms and funnel of the one have or have not their homologues in the other. The dorsal integument of a *Doris* and the cloak of a Whelk are both called "mantle," without any evidence to show that they are really homologous.

Nor do very much more definite notions seem to have prevailed with regard to the archetypal molluscous form, and the mode in which (if such an archetype exist) it becomes modified in the different secondary types. So far as our knowledge goes among other forms of animal life, we invariably find that, whatever the subsequent variations and aberrations, the primordial embryonic form has its parts arranged symmetrically about a given axis.

No one imagines the Pleuronectidæ belong to an asymmetrical type because they are asymmetrical in their adult shape, and yet there is no stronger evidence for the very common assertion that the typical form of the Mollusca is spiral or asymmetrical†.

This unsatisfactory state of our knowledge appears to me to result from two causes;

* Owen, Anatomy of *Spirula*, Voyage of Samarang, Zoology, p. 12.

† See Von Baer, Nova Acta Acad. Nat. Cur. vol. xviii. p. 753.

—first, from the want of a clear and definite conception of the fundamental varieties of molluscous structure, and of the nature of the changes in the relations of parts which constitute those varieties; and secondly, from the want of a due regard to the facts presented by the development of the different families, which must stand in the relation of cause to the varieties of form.

Now in order to the former end (the obtaining of a definite conception of the varieties of molluscous form), I propose to set forth the structure of certain Heteropoda and Pteropoda; pelagic animals so transparent, that a perfect knowledge of the arrangement of their parts may be arrived at by simple inspection, without so much as interrupting a beat of their heart.

Afterwards, I shall inquire how far the known laws of development account for these forms, and thence of what archetypal form they may be supposed to be modifications.

PART I.

I. *Anatomy of Firoloïdes* (Plate II. fig. 1).

The species of *Firola* which I examined appears to be identical with the *Firoloïdes Desmarestii* of MM. Eydoux and Soulbyet*.

The animal may be described as a transparent cylinder about an inch long, and so generally colourless as to be hardly distinguishable in the water, except by the incessant flapping of its flattened ventral appendage (*pp*).

The only parts which present any colour are the buccal mass, which is brownish; the eyes, almost black, and the mass of the liver, which is brownish green; further, the anus has a pinkish tint.

Attached by a narrow root or pedicle to the ventral surface of the cylindrical body is the broad cheese-cutter-shaped foot, or as I propose to call it, *propodium* (*pp*). Its posterior edge is quite sharp, and carries no sucker-like expansion. The anterior fifth, or thereabouts, of the animal is thinner than the rest of the body, and it narrows again towards its extremity, which is truncated, and forms a circular lip round the aperture of the mouth. Just behind the narrowed fifth, and towards the dorsal surface, we observe the eyes, and immediately below, and as if proceeding from them, are the tentacles, which are short and conical.

The posterior extremity also is abruptly truncated; its uppermost angle slightly projects, and viewed from above appears like a subspiral, richly ciliated band (*d*). Some little distance from this is the aperture of the anus (*a*).

From the two inferior angles, two tubular processes pass in the male (fig. 1). The right process ends in a globular body and is the penis (*p*), while the left (which I shall call the *metapodium*) is long and somewhat pointed (*mt*).

In the female there is only one process (the metapodium) (fig. 2, 3 *mt*) answering

* Figured by them in their beautiful plates illustrative of the Zoology of the Voyage of the Bonite.

to the left of the male, but a long cylindrical egg-tube frequently trails from the aperture of the oviduct (fig. 2).

Alimentary System.—This consists of,—1, the buccal mass; 2, the œsophagus and stomach; 3, the intestine and its termination, the rectum; 4, the liver; and 5, the salivary glands, which are very small and placed above the buccal mass, contrasting singularly with the very large salivary glands of *Atlanta*.

The œsophagus, stomach, and intestine form a straight tube running through the axis of the animal, and suspended by a ligament to the dorsal parietes (fig. 1); having reached the "nucleus," that is, the mass of the liver and ovary, the intestine bends up at a right angle, and so becomes the rectum, which terminates, as has been seen, upon the dorsal surface.

The Buccal Mass, or Tongue (fig. 1 *b*).—This is an oval brownish body, placed below the commencement of the œsophagus, and forming the floor of the cavity of the mouth. The following parts may be distinguished in this mass:—

1. Two ovoid compressed masses of thick-walled clear cells, which somewhat resemble cartilage. I shall call these the "lingual cartilages."

2. These give attachment to muscular fibres by their outer surface, and are enveloped in them. One portion of these fibres is inserted anteriorly into the parietes of the body, and acts therefore as a protractor. The rest are inserted into the edges of a thin plate, the "tongue-plate," which is closely applied to the whole of the upper and a part of the anterior lower surface of the cartilages, being as it were bent over their anterior extremities. The applied surfaces of the plate and of the cartilages are perfectly smooth, so that the former can play readily over the latter, like a rope upon its pulley. The upper surface of the tongue-plate carries in the middle a single row of tridentate teeth; outside these is a row of conical spines and broad flat-edged plates, and most externally there are one or more rows of recurved hooks, which, when the organ is at rest, lie over and nearly meet one another in the middle line.

When this organ is in action, it is commonly more or less protruded from the mouth by the protractor muscles; the large lateral spines of the tongue are divaricated (giving rise to that resemblance to the oral armature of *Sagitta* which has been remarked), so as to get all the teeth to bear; and then by the alternate action of the upper and lower sets of muscles inserted into the tongue-plate, a chain saw-like movement is communicated thereto, in consequence of which the teeth act as a rasp or saw upon any body with which they are brought in contact.

The buccal cartilages take no part in the movement of the tongue-plate, but simply act as its pulley.

The *Œsophagus* widens so gradually into the stomach, that no distinct line of demarcation can be drawn between the two, but the latter narrows suddenly into the intestine at a short distance in front of the "nucleus."

The *Liver* (*l*) is composed of several foliaceous masses containing many oil-globules; it opens by a wide duct into the angle of junction of the intestine and rectum.

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The Circulatory System (figs. 1, 2, 3, 6).—This consists of a very perfect heart with an aorta and its branches, but there is no trace of any venous system.

The heart lies anterior to and parallel with the rectum; its axis therefore is nearly at right angles with that of the body. It possesses two chambers, an auricle (*u*) and a ventricle (*v*). The auricle is large and somewhat elongated, extending above into the elevation which carries the subspiral ciliated band. Its wall is formed by branched and interlacing muscular fibres, which are attached partly to the parietes, partly to the walls of a contractile sac (*c*), to be mentioned presently.

The ventricle is almost globular, and has thicker walls, in which the separate muscular fibres are not distinguishable. The lips of the auriculo-ventricular aperture are prolonged on the ventricular side into two valvular folds. Below, the ventricle terminates in a wide aorta, which immediately gives off a large branch backwards to the hepatic and generative organs; then becoming much convoluted, it runs forwards along the intestine and stomach, passing between the latter and the pedal ganglia (fig. 6), and finally terminating, without much alteration in its diameter, in the buccal mass.

As it passes over the pedal ganglia it gives off a considerable branch, "the pedal artery," downwards to the foot; and this pedal artery, just before it enters the foot, gives off a long and delicate "metapodal" branch (*w'*), which passes backwards, parallel to the aorta, and finally terminates in the metapodium, figs. 2 and 3.

The mode of ending of the pedal artery is very remarkable, and physiologically speaking, almost unique (fig. 6). Having entered the foot, it ends suddenly, without narrowing, in a truncated open extremity (*y'*). In the living animal this open end possesses the power of contracting to a very great extent, so as almost to become closed; and its condition must necessarily exercise a very considerable influence upon the direction and rapidity of the animal's circulation.

*Firoloïdes** then affords the most complete ocular demonstration of the truth of M.-Milne Edwards's views with regard to the nature of the circulation in the Mollusca, that can possibly be desired. The perfect transparency of the creature allows the corpuscles of its blood to be seen floating in the visceral cavity between the intestine and the parietes, and drifting more or less rapidly backwards to the heart. Having reached the wall of the auricle, they make their way through its meshes as they best may, sometimes getting entangled therein, if the force of the heart has become feeble. From the auricle they may be followed to the ventricle, and from the ventricle into the aorta, whence they pass, some forwards, to the buccal mass, in which the aorta ends, and through whose tissues it pours them; some downwards, to pour out of the widely open end of the pedal artery, flooding the tissues of the propodium; and a small proportion passes directly backwards to the visceral mass and to the metapodium.

* A similar condition of the circulatory system has been observed by Nordmann, Quatrefages, Van Beneden and Allmann, in various Nudibranchiata, though perhaps not quite so distinctly.

Respiratory System.—So delicate a creature would hardly seem to need any special system of this kind, and I found no trace of such organs in any, even the freshest and most uninjured specimens.

In the nearly allied species *Firola Keraudrenii*, however, the gills appear as a row of conical processes, extending along the posterior edge of the body behind the anus; and in other species such processes develope accessory folds, until in *Carinaria* we find fully-formed branchiæ (see Eydoux and Souleyet). The ciliated subspiral band (*d*), which will be found to have its homologue in *Atlanta*, is the only structure which appears to be capable of assisting the respiratory function; but its small size must render it of very little importance.

Mantle.—There is no distinct mantle in *Firoloïdes Desmarestii*.

Carinaroides (Eydoux and Souleyet) evidently forms the transition from the Heteropods without a mantle to those with one. It is in this genus placed at the lower posterior angle of the body, and carries a minute shell; the branchiæ are developed between it and the anus.

In *Carinaria* there is a proportionably small mantle and shell, but it occupies a position more resembling that of ordinary Mollusks; and in *Atlanta*, as will be seen, the relative proportions of the mantle and body are pretty nearly those found in ordinary Gasteropods.

Contractile Sac or Urinary Organ (*c*, figs. 2, 3).—Between the rectum and the heart, and therefore bathed by the returning venous blood, there lies an elongated, flattened, delicate and transparent sac, whose walls are usually very much wrinkled and sacculated.

This sac opens by a rounded aperture in its upper part upon the right side of the animal, and is of course continually filled by the surrounding water. As the sac is incessantly contracting, however, this water must be continually renewed, and hence the organ, simple as its structure appears and small as its size may be, is probably a very efficient depurating agent*.

Considerations to be stated hereafter, lead me to the belief that it is in fact the urinary organ, at once kidney and urinary bladder.

Reproductive System.—Firoloïdes is dicœcious. The male may be distinguished at once from the female, by the peculiar penis (*p*) attached to the right posterior inferior angle of the body (fig. 4). It consists of two portions; the larger is cylindrical, but enlarged at its extremity into a globular head, from one side of which a small pointed process projects. The globular body contains many large cells as a sort of lining, and within these there is a cavity which communicates with the exterior through the pointed process. A vast number of small oval fatty-looking particles may be made by pressure to pass out from the cavity.

* In the 'Explication des Planches,' Eydoux and Souleyet call a similar organ in *Firola* "organe de la dépuration urinaire ?."

The smaller portion is like a trifid leaf; it is placed at the base of the former portion, and almost reminds one of the sculptor's vine-leaf*.

The *Testis* is not very easily to be distinguished from the liver, behind which it is placed, until the contained spermatozoa are recognized. It occupies about the posterior half of the nucleus. There is hardly any proper vas deferens, but the testis opens by a very short canal at the base of the penis.

The *Ovarium* (*o*) occupies a position similar to that of the testis (figs. 2 and 3). A wide oviduct arises from it about its centre, on the right side, and after making one bend passes downwards, and opens close to the base of the metapodium.

The ovarian ova were oval, about $\frac{1}{300}$dth of an inch in diameter, with a clear, delicate, germinal vesicle about $\frac{1}{600}$dth of an inch in diameter, and a pale, circular, clear, but thick-walled vesicular germinal spot about $\frac{1}{1000}$dth of an inch in diameter. In the oviduct the ova possessed either an entire granular yelk, in which I could not detect any germinal vesicle, or the yelk was broken up into two or more (but not many) spherical or subspherical masses, containing a clear vesicle, the embryo-cell.

In some individuals a long tube (figs. 2 and 5), half as long as the body or more, depended from the orifice of the oviduct. It was colourless and transparent, and appeared as if articulated from its membrane being thrown into regular annular folds.

This egg-tube contained a double series of ova, in which the yelks had undergone division into 8 to 15 masses of very variable size. The ova seemed to have become more divided the nearer they were to the distal extremity of the tube, but I could find none containing a distinct embryo.

The Nervous System (figs. 6 and 7).—Two three-lobed ganglia, closely applied together by their inner edges (fig. 7), are placed between the eyes. Each gives off several branches to the parietes and the following important trunks:—

1. A long branch forwards, which terminates in a small ganglion (β) placed in the angle of union of the œsophagus with the buccal mass, and joined to its fellow by a very short commissure beneath the œsophagus. From these "buccal ganglia" various small nerves are given off forwards to the buccal mass and parts about the mouth, and backwards, to the œsophagus.
2. A large optic nerve (*i*).
3. A nerve to the tentacle.
4. A small nerve from the under surface, which terminates in the auditory sac (*j*).
5. A large and long commissural branch which runs backwards and downwards past the stomach, to unite with the pedal ganglion of its side.

The *Pedal Ganglia* (*y*) are two large ovoid masses in contact by their inner edges.

* According to Milne-Edwards (Sur divers Mollusques, Annales des Sciences, 1842), a perfectly similar penis is found in *Carinaria*. He states, however, that the vas deferens traverses one portion of this organ, which is certainly not the case in either *Firoloïdes* or *Atlanta*.

They give off—

1. Two branches downwards to the propodium.

2. Two branches upwards to the dorsal parietes.

3. Two large branches, which run at first separately below the stomach, and then unite to form a single trunk. This runs along the stomach and intestine, sometimes twisting round them and giving off branches to them and to the parietes; and on the intestine it separates again into two chords, which join two small ganglia (3) placed between the aorta and the intestine; one lies on the aorta, the other between this vessel and the intestine, and they are connected by a commissure. From the former of these ganglia, which is the smaller, two nerves pass upwards and join a flattish mass placed immediately beneath the 'subspiral ciliated band.' There was an obscure appearance of branches radiating from this mass, and it is probably ganglionic.

Organs of Sense. The Eyes (fig. 8).—The eyes are very perfectly organized; each eye is contained within a chamber, excavated in a papilla, whose convex wall forms a sort of supplementary cornea, answering to the cornea of Cephalopoda, or to the corresponding cutaneous cornea of the Gasteropoda.

Their eye-proper is suspended within this chamber by a number of irregular muscular bands, which stretch from it to the walls of the chamber, and perform the function of *oculi-motores*. The optic nerve penetrates the inner wall of the chamber and enters the eye from that side.

The eye-proper is elongated and somewhat hour-glass-shaped, being contracted just behind the crystalline lens. The constriction divides the eye into two portions, an internal and an external. The latter is almost spherical, and is formed by the true cornea, which is much thicker in the middle than elsewhere, so as to present a meniscus section. Behind, the cornea is continuous with the sclerotic coat, which is thick, and seems to be continuous with the neurilemma of the optic nerve.

The crystalline lens is spherical, and is separated by a very small interval from the cornea, so that there is hardly any anterior chamber of the eye. There is no iris, but the inner surface of the posterior chamber is coated by a layer of dark chocolate-coloured pigment*.

The Auditory Vesicles (*j*), fig. 7.—These lie behind and a little below the cephalic ganglia. Each is a spherical vesicle, about $\frac{1}{300}$dth of an inch in diameter. Its walls are irregularly thickened here and there, and it contains a spherical otolithe of about half its diameter. I was unable to perceive any motion in the otolithe. The auditory nerve is a delicate thread arising from the under surface of the supra-œsophageal

* I do not see that the eyes of Heteropoda are so "peculiarly formed" as Krohn has it (Ferner Beitrag zur Kenntniss des Schneckenauges. Müller's Archiv, 1839). What I have described as the true cornea, is by Krohn considered as an anterior portion of the vitreous humour; such an arrangement would of course be very peculiar, but I think that my account is correct. The eye, it would appear, projects much less in *Carinaria* and *Pterotrachea*; and in the latter, according to Krohn, there is even a rudimentary eyelid.

Krohn does not say anything about the muscles of the eye in these two genera.

ganglion, just in front of the commissural cord. It appears to terminate suddenly on entering the vesicle.

This origin of the auditory nerves from the cephalic ganglia, *when the pedal ganglia are well-marked and placed below the œsophagus*, is a circumstance common to all the Heteropoda*, and, so far as I am aware, altogether peculiar to them among the Mollusca. The only writers who appear to have been struck by it are MM. Frey and Leuckart: they say that the auditory organs are united with the supra-œsophageal ganglia "only when the lower œsophageal ganglia are wanting (except in *Carinaria*, in which the great length of the lateral commissures of the œsophageal ring appears to have made such a position necessary)." (Beiträge, p. 55.) I must confess I do not see the force of this explanation; and the lower œsophageal ganglia are never "wanting," though they may be united with the upper ones.

II. *Anatomy of Atlanta.* (Plate III.)

This is a very small and very beautiful pelagic mollusk, with a shell not more than one-fourth of an inch in diameter. It appears to be identical with the *Atlanta Lesuerii* of Eydoux and Souleyet. Its structure resembles that of *Firoloïdes* in all its essential points, and the transition between the latter and *Atlanta* is complete through such forms as *Firola*, *Carinaroides* and *Carinaria*.

The shell is flattened and spiral, none of the whorls projecting beyond the plane of the outermost. The aperture is notched on its dorsal edge, and a deep thin crest surmounts the outer whorl, and is generally broken in several places. The surface of the shell is marked by delicate transverse striations.

The outer fourth of the outer whorl of the shell is occupied by the mantle, the rest of the spire containing the viscera.

When protruded, the body of the animal is as large as the shell and appears trifid; the large head forming the anterior division, the "fin" the middle, and the "tail," with its operculum, the posterior division.

The head is large and subcylindrical. Its anterior extremity is formed by a circular lip surrounding the month. The eyes are placed far back, and the longish conical tentacles proceed from the anterior part of their base.

The fin or "propodium" (*pp*) is flattened and fan-shaped; its edge is provided with many long and delicate hairs, and its surface is covered with little asperities. Just below its point of attachment, the posterior edge of the propodium carries a cup-shaped disc (*ms*), also fringed with long hairs. This is commonly called the "sucker," and has no representative in *Firoloïdes*. It may be called the *mesopodium*.

The "tail" or *metapodium*† (*mt*) is subcylindrical at its base, but becomes flattened

* Compare Milne-Edwards, Sur divers Mollusques, Annales des Sciences, 1842, and the figures of Eydoux and Souleyet, so often referred to.

† That this is the same organ as the metapodium of *Firoloïdes*, will be obvious upon comparing the different forms which it assumes in *Carinaria*, *Carinaroïdes* and *Firola*.

and acuminated inferiorly. The elongated lanceolate transparent operculum is fixed upon its posterior surface.

The animal moves by the vigorous flapping of its fin. When it withdraws within its shell the head is just retracted, then the fin is folded in, and finally, the tail with its operculum covers up the whole.

The male is distinguished from the female by the presence of a peculiar leaf-like penis (*p*), which is attached upon the right side of the body just above where it divides into the three portions of the foot, fig. 1.

The *Alimentary Canal* commences above an oval buccal mass, widens gradually into the stomach, then narrows again and opens into a quadrangular sac, which communicates with the liver. From the anterior and upper part of this sac the rectum is continued and runs forward to the upper and dorsal part of the branchial cavity, in which it terminates by a tubular anus.

The mechanism of the tongue exactly resembles that of *Firoloïdes*. Two long cylindrical salivary glands (*f*) open into the anterior part of the œsophagus. They are simple cæca lined by a thick epithelium.

The *Liver* (*l*, fig. 3) is a wide conical sac with sacculated and glandular walls; its communication with the quadrangular dilatation of the intestine is so wide that it may almost be considered as a diverticulum thereof, and it extends back as far into the spire of the shell as any of the viscera.

The rectum is of a pinkish colour, and is richly ciliated internally.

Circulatory System (figs. 2, 3, 4).—The heart resembles that of *Firoloïdes*, and consists of an auricle (*u*) and a ventricle (*v*). It lies parallel to the rectum, with the auricle forwards at the base of the mantle-cavity, and the animal is therefore prosobranchiate. The aorta proceeds from the apex of the ventricle, and immediately after its origin divides into two branches, one of which runs backwards to the visceral mass, while the other passes forwards close beneath the stomach, until it terminates in the buccal mass. After passing over the subœsophageal ganglia, it gives off a downward branch to the fin, but I did not observe the peculiar termination of this artery which obtains in *Firoloïdes*; this perhaps may be accounted for by the greater muscularity of the fin in *Atlanta*, rendering it less transparent. The venous blood has no distinct channel, but returns to the heart by the cavity of the body. The returning current of blood-corpuscles is very obvious; they seem to pass quite freely in all directions round the intestine, aorta and nervous centres, the general tendency being always backwards towards the heart.

Respiratory System.—Very distinct gills are figured by Eydoux and Souleyet in most Atlantæ, but their presence in this species was decidedly exceptional, the majority of specimens presenting no trace of them. Once I noticed a bundle of long branchial filaments depending from the wall of the mantle-chamber; and in another case rudimentary and undeveloped short processes of the same kind were to be seen; they contained canals, through which a small portion of the returning venous blood was diverted, fig. 4.

The *Mantle* is very well developed; a peculiar thickened and ciliated band crosses it transversely, and seems to be the homologue of the subspiral ciliated band in *Firoloïdes* (*d*).

Contractile Sac.—This resembles the corresponding organ in *Firoloïdes*; it lies between the rectum and the heart, and opens into the bottom of the chamber of the mantle by a well-defined oval aperture, figs. 3 and 4 *c*.

Generative Organs.—The ovary or testis is an elongated mass corresponding to the liver, and occupying the inner and right half of the visceral mass, fig. 3 *t*.

The *Ovary* consists entirely of a mass of ova in course of development, with their characteristic germinal vesicle and spot. The oviduct commences at its anterior larger extremity; it is very wide and passes forwards, forming many convolutions, and terminates in the mantle-cavity by the side of the anus.

The *Testis* contains a mass of small cells and spermatozoa in various stages of development. The vas deferens leads from its anterior extremity, and before terminating in the cavity of the mantle, dilates, occasionally forming thus a dark spherical vesicula seminalis, *s*, fig. 3.

There is a kind of penis attached to the right side of the neck of the animal just above the foot (*p*, fig. 1): it is composed of two portions arising from a common base. The anterior and inner is like a three-pointed leaf; a cæcal ciliated canal runs along its centre. The posterior portion is a tubular cylindrical process, with a kind of ciliated cup at its extremity (fig. 5): a conical body projects into this below. The tube is nearly filled with small oval granules. The resemblance between this and the penis, which has been described in *Firoloïdes*, cannot be misunderstood, and the position of the organ in *Atlanta* corresponds with that in *Firoloïdes*, if we consider the left filamentous process in the latter to be the metapodium. That it is so, is demonstrated not only by the distribution of the metapodal arteries, but by an examination of the intermediate genera above mentioned.

Nervous System (figs. 2 and 6).—This consists of two trilobed supræsophageal ganglia (fig. 6), which correspond to those of *Firoloïdes*, and give off similar nerves; but in addition their posterior lobes give off each a long nerve*, which runs back upon the stomach, and below its posterior narrowing, between this and the aorta, joins with its fellow in a small ganglion (not figured by Eydoux and Souleyet); some branches pass from this to the viscera, and two or three run in the substance of the mantle to the "ciliated band," fig. 4.

The commissural cords which unite the supræsophageal with the subœsophageal or pedal ganglia, are at first double (fig. 6), but afterwards unite into one. They are connected with the subœsophageal or pedal ganglia (*y*), two large oval masses from which several branches are given to the different parts of the foot; and each gives off one long cord which runs along the lower surface of the intestine, and probably joins the ganglion upon the aorta before mentioned.

* In *Carinaria* a similar commissural nerve, between the cephalic and the parieto-splanchnic system of ganglia, has been shown to exist by Milne-Edwards (*loc. cit.*), but I could find none in *Firoloïdes*.

The *Eyes* (*i*, fig. 6) resemble those of *Firoloïdes*, except that their pigment is black.

The *Auditory Vesicles* are spherical and about $\frac{1}{350}$th of an inch in diameter. Each contains a single strongly refracting globular otolithe of about $\frac{1}{800}$dth of an inch in diameter. In some cases this had a slow movement of rotation upon its axis, fig. 6, *j*.

Now in regarding *Firoloïdes* and *Atlanta*, whose structure has just been described, as illustrations of a typical form, the following circumstances appear to me to be of importance:—

1. The intestine is bent dorsad, or towards the side on which the heart is placed. The visceral mass is situated below and behind the posterior portion of the alimentary canal; it may be called a post-abdomen.

2. *Atlanta* is prosobranchiate; *Firoloïdes* is neither opisthobranchiate nor prosobranchiate.

3. The foot consists of three parts, the propodium, mesopodium and metapodium, in *Atlanta*; but of these the mesopodium disappears in *Firoloïdes*, and the metapodium becomes very rudimentary.

4. The auditory organs appear to be connected with the cephalic ganglia.

5. The animals are unisexual.

III. *Anatomy of Pteropoda.* (Plate IV.)

The variation of form undergone by the members of this group is perhaps greater than that which takes place in any other, except it may be the Nudibranchiata, and hence their structure is particularly instructive.

Three very distinct modifications of the type present themselves at first sight. The first is characterized by the non-development of the mantle and the full development of the foot, ex. *Pneumodermon*, *Clio*, fig. 1.

The second, by the great development of the mantle, by its cavity opening upon the ventral surface, and by the minuteness or absence of the mesial portion of the foot, ex. *Cleodora*, fig. 4.

The third resembles the second, but the mantle-cavity is placed upon, or at any rate opens upon the dorsal surface, ex. *Spirialis*, *Limacina*.

1. It is very remarkable that Cuvier should not have recognized in the "espèce de menton," and the "deux petits lèvres*" of *Pneumodermon*, nor in the "deux tentacules triangulaires" of *Clio*†, the homologues of the foot of the Gasteropoda. In fact it was on the strength of their having no such appendage that he founded his new order of Pteropoda‡, and yet the resemblance of the inter-alar appendages in these two genera§ to the foot of Gasteropods is so striking as at once to point to their real nature.

* Mém. sur le Pneumoderme, p. 7.

† Mém. sur le Clio, p. 6.

‡ Mém. sur le Clio, p. 9; sur l'Hyale et le Pneumoderme, p. 10.

§ This is fully recognised by Leuckart, "Ueber die Morphologie," &c. p. 149.

In truth, the foot, though very small in these genera, is exceedingly well-marked, and shows a clear division into mesopodium and metapodium. It may be a matter of doubt whether the propodium is developed or not, and this question can be settled by embryology alone; but for the present, I think, it may be fairly presumed that it is represented by the tentaculigerous hood of *Pneumodermon* and by the tentaculigerous lobes of *Clio*; following in this case a very common tendency (exemplified in all the Cephalopods and in many Gasteropods) to become developed over and in front of the mouth*.

As Cuvier demonstrated, there is no "mantle" in *Pneumodermon* and *Clio*†; the body of these mollusks answering precisely to that of a *Firoloïdes*. The relation of the gill-laminæ and of the small anomalous shell in *Pneumodermon* sufficiently corroborates Cuvier's view. Gills are never placed upon the outer surface of a mantle; and if anything answers to such an organ it must be the small space covered by the rudimentary shell, so that the relations of the parts are, in fact, similar in *Pneumodermon* to what we find in *Firola* and *Carinaroïdes*.

Finally, new parts, the "alæ," make their appearance in these genera and give its character to the order (figs. 1, 2, 3, 4, 7, *ep*).

Considering the position and relation of these organs as distinct developments from the upper part of the sides of the foot, and the fact that their nerves arise, like those of the foot, from the pedal ganglia, I propose to consider them as parts of the foot and to call them the "epipodia." It has been long since shown by Van Beneden and others that they have nothing to do with the respiratory function.

In this subtype the intestine opens on the right ventral side of the neck, and dissection shows its first bend to be ventral, that is, towards the side of the pedal ganglia.

2. The genus *Psyche*‡ or *Euribia* offers a very interesting transition from the foregoing to the second subtype. This genus is commonly said to have a cartilaginous shell, but this so-called shell appears, upon careful examination, to be only the thickened integument of the body; it is not secreted by a true mantle, like that of *Cleodora*, &c. The notion of a shell has arisen seemingly from the fact that a sort of cleft exists anteriorly from which the locomotive organs of the animal can be protruded and into which they can be retracted, but at the margin of this cleft the softer

* The origin of the nerves of the acetabuliferous tentacula may probably throw some light upon this matter; I have not had the opportunity of dissecting sufficiently large specimens of either *Pneumodermon* or *Clio*, carefully, with regard to this especial point. From the figures of Eydoux and Souleyet, one would be led to believe that the nerves of the acetabuliferous tentacles arise from the cephalic ganglia, which would be a very great objection to the view advocated above, since all the other parts of the foot, the mesopodium, metapodium and epipodium are supplied by the pedal ganglia. (See Eydoux and Souleyet, plate 15. fig. 30, and plate 15 bis, fig. 8.)

† Eydoux and Souleyet, however, call it "manteau" in the description of their figures. Leuckart also opposes Cuvier's view, but I think without reason. (*Op. cit.* p. 146 note.)

‡ My species appears to be the *Euribia Gaudichaudii* of Eydoux and Souleyet.

parts of the body are continuous with the harder, just as the body of a Polyzoon is connected with its cell.

In some individuals I have observed the posterior extremity of the body to be surrounded by two circlets of cilia*.

The head of the animal is provided with two very large tentacles†, which carry a large process upon the inner side of their base, and rudiments of eyes upon the outer. Between the tentacles on the ventral side are two projecting lips with the aperture of the mouth between them, fig. 3.

Behind the mouth there are two lobes, separated by a deep notch; these are the two portions of the mesopodium which had begun to be separated in *Clio*. Behind these, again, there is a single tongue-shaped lobe, the metapodium, which is continuous on each side with two elongated and expanded epipodia.

There are no gills, and the anus opens ventrally upon the left side.

From this genus, to that called *Criseis* by Rang, but which Eydoux and Souleyet unite with *Cleodora*, the transition is very easy, figs. 6, 7.

In these forms there is an elongated conical shell, narrow and straight, or wider and slightly curved at its extremity. The body puts one in mind of that of a Cephalopod, being enveloped in a wide mantle, which is united to the body on the dorsal side only (fig. 6). The wall of the mantle is very thick, so that it presents a wide aperture always open upon the ventral side. Its free edge is, as it were, cut down upon its dorsal side, so that ventrally it is considerably longer. On the right side this prolonged portion has a rectangular edge, but upon the left it forms a sort of ram's-horn process‡. The lower part of the inner surface of the mantle is richly ciliated, and is raised into a number of transverse ridges, which must probably be considered to be rudimentary gills.

The head and wings are united with the part of the body covered by the mantle, by a narrow neck; compared with *Euribia*, the change in form is such as would be produced by a lateral expansion of the foot. Behind the mouth is the wide metapodium, and on each side of it are the broad epipodia continuous with the metapodium. About midway between the mouth and their margin the epipodia carry a small triangular lobe (*ms*), which evidently represents one-half of the mesopodium; and nearly at the same level, on their anterior edges, they present two small curved and pointed processes, the representatives of the large tentacles of *Euribia*. Two minute papillæ, the rudiments of the eyes, are placed upon the dorsal surface just behind the anterior edge of the alæ (*i*).

* It is a very interesting fact that Professor Müller has found the larvæ of *Pneumodermon* to be provided with similar ciliated bands, Ueber die Entwickelungs-formen, &c. Monatsbericht d. k. Akad. d. Wiss. zu Berlin, October 1852.

† These are called "branchies" by Eydoux and Souleyet (pl. 15.), but why I cannot divine, since these organs are certainly homologous with the tentacles of *Cleodora*.

‡ Is this to be compared with the small posterior curved process of the edge of the mantle in Gasteropteron?

The œsophagus takes a straight course backwards from the mouth, which contains a minute lingual prominence, and widens gradually into a pyriform muscular gizzard, which is provided with two strong curved and conical teeth. The intestine passes from the narrow pylorus, and preserving the same width throughout, bends downwards towards the ventral side, and ultimately terminates in the cavity of the mantle a little to the left of the mesial line, fig. 6.

Just behind the pylorus a very long straight cæcum is given off, and sometimes there is a short one in addition by the side of it. The parietes of these sacs are glandular.

A long "columellar" muscle attaches the animal near to the apex of its shell, and then passes down into the foot, where it spreads out.

The position of the heart varies remarkably in this genus, and this variation is still more remarkable, if, with Eydoux and Souleyet, we consider it to be one with *Cleodora*.

In *C. aciculata* (figs. 6, 7) the mantle-cavity extends considerably beyond the transversely-barred portion of the mantle, and the base of the auricle abuts upon its lower posterior portion. The apex of the heart points backwards and a little to the left side, and in M. Milne-Edwards's arrangement the animal would be prosobranchiate. In *C. virgulata* (E. and S.) the base of the auricle lies behind the right posterior portion of the mantle-cavity, and the apex of the ventricle points directly to the left; it is therefore neither prosobranchiate nor opisthobranchiate.

In *Cleodora curvata*, on the other hand, as will be seen immediately, the base of the auricle is posterior and the ventricle points forwards; it is opisthobranchiate, figs. 4 and 5.

In this one genus, then, we have every transition from the prosobranchiate to the opisthobranchiate type of organization.

The aorta is too delicate to be readily traced in *C. virgulata* and *C. aciculata*. It may however be seen passing through the nervous ring and bifurcating for the epipodia, fig. 7 *w*. There is no rudiment even of a venous system.

The *Cleodora curvata* (figs. 4 and 5) (one of the true *Cleodoræ* as formerly defined) forms a transition from the preceding species to *Hyalæa*. It has the general organization of the former, with the flattened shell more or less fissured laterally, and the filiform appendages to the mantle, of the latter.

The alary expansion forms a more rounded disc than in *C. aciculata* and *virgulata*, the metapodium having become widened out and almost undistinguishable from the epipodia. The triangular lobes, rudiments of the mesopodium, have disappeared.

The intestinal canal resembles that of the two former species; its flexure is ventral, and the anus opens into the cavity of the mantle on that side. The long cæcum has orange-coloured glandular parietes.

The position of the heart has been described. It is comparatively large, and the aorta may be readily traced from it, passing forwards over the stomach and through

the nervous ring, and eventually dividing into two branches, one for each epipodium.

There is a more distinct rudiment of a venous system in this mollusk than in *Firoloïdes* or *Atlanta*. A wide canal traverses the mantle towards its upper part; it is crossed by various muscular bands. Another distinct canal can be traced from the auricle towards the right side, skirting the lower border of the branchial chamber. Whether it becomes continuous with the right extremity of the previous canal or not, I could not certainly determine. The blood flows from both ends of the first-mentioned canal towards the auricle, but on the left side there does not appear to be so distinct a venous canal as on the right.

In all species of *Cleodora* there is an elongated sac, in its structure, contractions, and position relatively to the heart, exactly resembling that of the Heteropoda. It communicates by a small aperture with the cavity of the mantle.

The *nervous system* in all these species consists of three ganglia on each side of the œsophagus. Four of these form a mass, placed entirely below the œsophagus, and the other two, placed in contact with and immediately above them at the side of the œsophagus, are united above by a broad flattened supraœsophageal commissure.

The upper (*cephalic*) ganglia give off two principal branches to the rudimentary eyes and tentacles. The anterior pair of the lower mass (the *pedal* ganglia) give off branches to the epipodia and expansion of the foot generally; posteriorly they carry two small auditory vesicles, with many otolithes.

The posterior (*parieto-splanchnic**) ganglia give off their principal branches to the mantle.

The aorta passes between the pedal and parieto-splanchnic ganglia.

3. I have mentioned that a third subtype appears to be formed by *Spirialis* and *Limacina*, which are the only Pteropods with spiral shells. *Spirialis*, again, is the only Pteropod with an operculum. But a more important difference for my present purpose consists in the fact, that in these genera the mantle-cavity (and with it the anus) opens on the dorsal side of the animal. I have not myself been fortunate enough to obtain specimens of these genera, and as the attention of those anatomists who have examined them does not appear to have been specially directed to this point, it is impossible to make out with certainty whether the first flexure of the intestine is also dorsal, or whether, as in all other Pteropods, it is ventral. I cannot think that any real variation will be found to occur among closely allied forms, in a matter so fundamentally connected with their whole structure and mode of development; and I would suggest that here also the bend of the intestine is truly ventral, but that by a continuation of the process by which the anus is thrown to the left side in *Cleodora* and to the right in *Pneumodermon*, it (with the branchial cavity) is thrown to the dorsal side in *Limacina* and *Spirialis*. Such a change would be completely paralleled by the arrangement of the parts in the Ascidians, where the first bend of the intestine is dorsal; but the cloaca, which corresponds to the mantle cavity, opens on

* See below, p. 54.

the ventral side, carrying the anus with it; and even in other Pteropoda we find changes in the arrangement of the mantle-chamber, which to a great extent modify, without however essentially altering, the normal arrangement, *e. g.* in *Hyalæa* and *Cymbulia*, where the posterior extremity of the mantle-chamber extends up to the dorsal surface.

Furthermore, the position of the heart, which remains on the ventral side in *Spirialis* (E. and S., plate 11. p. 13, &c.), greatly strengthens this view of the case.

Leaving this question in abeyance until further light is thrown upon it, we may, I think, enunciate the following propositions with regard to the Pteropoda corresponding to those in which the organization of the Heteropoda was summed up:—

1. The intestine is bent towards the ventral side; the visceral mass is placed above, and in front of the anus; it may be called an abdomen.

2. Some Pteropoda are prosobranchiate, others intermediate, others opisthobranchiate.

3. The foot consists of four parts:—three, the propodium, mesopodium, and metapodium, such as are found in the Heteropoda; and a fourth, the epipodium, not found in the Heteropoda. All of these parts (propodium?) may be distinguished in *Pneumodermon* and *Euribia*, while all but the epipodium and metapodium have disappeared in *Cleodora*.

4. The auditory organs are connected with the pedal ganglia.

5. The Pteropoda are hermaphrodite*.

PART II.

The Heteropoda and Pteropoda, whose anatomy I have just endeavoured in a very general way to sketch and illustrate, may be regarded, in some respects, as opposite poles of the development of the archetype of the Cephalous Mollusca. We have now to consider what that archetype is, and by what process it has become modified into the actual forms which have been described; and with the solution of these questions is connected the meaning and justification of certain new terms of which I have made use.

The most proper way of proceeding in this matter would of course be, to trace the *development* of the Heteropoda and Pteropoda. Unfortunately, however, I have had no opportunity of doing this myself; and so far as I am aware, there is no account of the embryogenesis of Mollusks belonging to either of these classes extant†.

* This, it will be observed, is here stated for the first time. In the Heteropoda the nature of the generative system has been a matter of controversy, and I therefore gave an account of it at length in *Firoloïdes* and *Atlanta*. The hermaphrodism of the Pteropoda, on the other hand, is well-known, and a description of their generative organs would only have led to details without any morphological bearing.

† Since the above paragraph was written, this hiatus has been filled, so far as the Pteropoda are concerned, by Vogt (Bilder aus dem Thierleben, p. 289) and by Johannes Müller (Ueber die Entwickelungs-formen einiger niedern Thiere. Monatsbericht d. k. Akad. zu Berlin, October 1852).

But in any natural group of animals the grand laws of development and growth are so uniform (the uniformity in fact constituting the true bond of union of its members), that this want may be supplied by the very full information we possess with regard to other Mollusca. If from these data certain general propositions can be established, it will, I think, be perfectly fair to make these propositions the basis whence deductively to explain and account for facts of organization whose absolute genesis is not known.

The development of the Cephalopoda, Pulmonata, Nudibranchiata, and Tectibranchiata, has been very carefully made out by Kölliker, Van Beneden and Windischmann, Schmidt, Gegenbaur, Sars, Nordmann, Vogt, Reid, and others. From their observations the following generalizations may be very safely made.

1. The development of a Mollusk commences on the hæmal* side, and spreads round to the neural side, thus reversing the process in Articulata and Vertebrata.

2. In all Mollusks the axis of the body is at first straight, and its parts are arranged symmetrically with regard to a longitudinal vertical plane, just as in a vertebrate or an articulate embryo†. Plate V. fig. 1.

3. The subsequent bent, spiral, or otherwise unsymmetrical arrangement of the parts of the body in Mollusca, depends upon the development of one part at the expense of, or disproportionately to, another; and this asymmetrical over-development never affects the head or the foot of a Mollusk, but only a portion, or the whole of the hæmal surface. Plate V. figs. 2–8.

4. It is to this portion, and its often free projecting edges, that we can alone properly apply the term "*mantle*." When this outgrowth takes place before the anus, I propose to call it an *abdomen*; when it takes place behind the anus, a *post-abdomen*.

5. All embryological evidence goes to show that the Cephalopoda and Pulmonata develope an *abdomen*. The intestine becoming drawn into the abdominal sac becomes in consequence bent towards the neural side. Plate V. figs. 2–5.

6. On the other hand, all the evidence hitherto obtained with regard to the de-

* This very remarkable law has not, it appears to me, received its due importance at the hands of those distinguished anatomists, Kölliker (for the Cephalopoda), Van Beneden and Windischmann and Gegenbaur (for the Pulmonata), Vogt (for the Nudibranchiata), and Leydig (for the Pectinibranchiata), from whose observations I deduce it. Vogt, however, observes that the order of appearance of organs in the Mollusca is the inverse of that in the Vertebrata; and with regard to the point from whence development commences, he says, "Ce point est facile de trouver, il est situé en arrière des roues a peu près sur la ligne de jonction entre la partie céphalique et la partie ventrale, et même un peu en arrière de cet dernière sur la partie abdominale même," p. 39.

I use the terms *hæmal* and *neural* here to avoid the ambiguity of dorsal and ventral, which have opposite meanings when applied to the Vertebrata and the Invertebrata. The hæmal side is that upon which the vascular centre is developed, it is the dorsal side of Articulata, the ventral of Vertebrata. The neural side is that upon which the nervous centres are developed; it is the dorsal side of Vertebrata, the ventral of Invertebrata.

† "Instead of the radial type of development we meet quite unmistakeably with a lateral symmetrical type; instead of the extended form of the body we find a short compressed body without repetition of segments or lateral appendages."—R. Leuckart, Morphol. p. 125.

velopment of the Nudibranchiata, Tectibranchiata and Pectinibranchiata, tends to the conclusion, that in them the visceral mass is thrust out *behind* the anus; is in fact a *post-abdomen**. Plate V. figs. 6–8.

A little consideration will show that the intestine drawn into this must become bent towards the *hæmal side*, as in fact it is in the embryos of all three groups†.

Upon embryological grounds, then, we should establish two great primary modifications of the molluscous archetype; the one characterized by the development of an *abdomen*, and a consequent *neural* flexure of the intestine; the other marked by the development of a *post-abdomen*, and the consequent *hæmal* flexure of the intestine.

But these modifications of anatomical structure exactly correspond with those which I have already demonstrated, upon anatomical grounds, to occur in the Pteropoda and Heteropoda; and I trust I am not overstepping the bounds of legitimate analogy in assuming that the anatomical fact of a neural flexure indicates the embryological development of an abdomen; that of a hæmal flexure, the development of a post-abdomen; and that therefore the Pteropoda fall into the same category with the Cephalopoda and Pulmonata; the Heteropoda into that of the Pectinibranchiata, Tectibranchiata and Nudibranchiata.

It is remarkable, that, as regards the flexure of the intestine, similar contrasted modifications of the archetype take place in those animals which are the nearest allies of the Mollusca; I mean the Ascidians and Polyzoa, the Molluscoïdes of Milne-Edwards. In each of these groups the intestine is always bent upon itself; but while in the Ascidian the bend is always *hæmal*, in the Polyzoon it is *neural*. The latter fact is evident to any one who will examine a Polyzoon; the former may seem at first sight to be contradicted by the circumstance, that the ganglion in the Ascidians is placed between the cloacal and branchial apertures. However, as I have endeavoured to show elsewhere‡, whatever be the position of the anus in the Ascidians, the first bend of the intestine is always hæmal. I have already referred to their probable analogy with *Spirialis* in this respect.

Having now determined the changes which take place in the axis of symmetry of the Mollusca, let us examine into those undergone by their principal external organs.

Whether we have to do with a Cephalopod or with an ordinary Mollusk, the first step in development is the separation of the blastoderm into a central elevation, the

* See particularly Leydig, *Ueber Paludina vivipara*, Siebold and Kölliker's Zeitschrift, 1850, where the thrusting forwards of the anus by the development of the mantle is particularly shown, p. 142.

"A considerable change in the position of the anus takes place when the fold of the mantle becomes formed and moves forward, because thereby the intestine and anus are also thrust forward, and to the right side."

† The development of the Pectinibranchiata cannot be said to have been carefully worked out yet, with the exception of that of *Paludina*, but what has been done tends to the conclusions above stated.

‡ Upon the Anatomy and Physiology of *Salpa* and *Pyrosoma*, Philosophical Transactions, 1851, and in a "Report upon the Structure of the Ascidians," read before the British Association, September 1852. The law as regards the Polyzoa was first enunciated by Professor Allman, "On the Homology of the Organs of the Tunicata and Polyzoa," Trans. Royal Irish Acad. vol. xxii.

mantle, and certain lateral portions. Now these portions become in the Gasteropoda, the head and foot; in the Cephalopoda, the head and arms. It follows therefore that the arms of the Cephalopod are homologous with the foot of the Gasteropod.

Again, in the Cephalopod an eminence becomes developed along two lines, which run on each side of the upper part of the "lateral expansions" and meet behind the head; along the anterior portion of this line the eminence remains as a slight ridge, which afterwards becomes one of the muscles of the funnel; along the posterior portion of the line a considerable process is developed, and, uniting with its fellow, becomes the funnel.

In the Gasteropod, it is along the *anterior* halves of two corresponding lines that processes are developed, which become the ciliated alæ or vela of the embryo. The line in question I propose to call the *epipodial line*, and whatever is developed along that line I consider to be the epipodium, or a portion of it. I do not venture upon such a refinement at present, but I think it *probable*, that as we have distinguished three portions in the foot, so it will be necessary to distinguish three portions in the epipodium; anterior, middle and posterior. For instance, in the Cephalopoda the posterior portion only is developed as the funnel; in the Gasteropod larvæ the ciliated vela are the homologues of its anterior portion. The palmated lobes of the Turbinidæ, the "lobes of the mantle" of *Aplysia*, appear to be developed from the whole epipodial line, while it is apparently the middle epipodium alone which is developed into the "wings" of the Pteropoda.

All traces of the epipodium appear to have vanished in the majority of the Pectinibranchiata*.

Of all mollusks *Atlanta* possesses the best developed *foot*-proper, and has its parts

* Leuckart and Lovén have enunciated very different views with regard to the homologies of the external organs of the Mollusca, to which it seems proper I should refer.

Leuckart, for instance (*op. cit.* pp. 155–59), considers that the anterior cephalic lobes of the embryo Cephalopod answer to the cephalic velum of Gasteropoda; the posterior cephalic lobes to the alæ of Pteropoda, while the funnel corresponds with the middle lobe of the foot. The arms he considers to be peculiar structures, mere appendages to the cephalic lobes.

If the halves of the funnel, however, answer to the middle lobes of the foot, how is it that they unite upon the dorsal surface of the neck? If the anterior cephalic lobes answer to the vela of Gasteropoda, how is it that the latter disappear, and do not contribute to the formation of the head in Gasteropoda? Finally, it must be remembered that the arms of the Cephalapoda arise quite independently of the cephalic lobes, the first developed arms being those most distant from the head.

Leuckart considers that the oral lobes of the pulmonate embryo are the homologues of the ciliated vela of Gasteropoda. But their position and number are against this view. It seems to me that these oral lobes correspond with the cephalic lobes of the embryo Cephalopod, and it has been well shown by Gegenbaur (*op. cit.*) that the whole so-called "yelk-sac" of the Pulmonata is the true homologue of the vela in Pectinibranchiata; the "ciliated bands" of Van Beneden and Windischmann turn out to be Wolffian bodies, and to be *internal*, not external organs.

The common view, that the alæ of the Pteropoda are the persistent vela of the embryo, is, so far as I am aware, unsupported by any evidence. Embryology teaches us hitherto that the anterior part of the epipodium

best specialized and separated. In the special description of *Atlanta* names have been given to these parts, whose appropriateness is I hope obvious.

From this highly developed condition of the foot, to its diminished state in *Glaucus* and its total absence in *Phyllirrhoë*, we have every gradation. The various portions are still to be distinguished in *Pteroceras* and the *Strombidæ*, but lose their distinctness for the most part in other Gasteropoda. However, the propodium is still marked off by a transverse fissure in *Oliva* and *Ancillaria*, and attains a great development in size; a peculiarity which is still more remarkable in *Natica* and *Sigaretus*. In both these genera it shows a tendency to invest the head. In the Cephalopoda, the anterior arms, which must be considered as the propodium, fairly unite in front of the mouth, and it seems very possible that the cephalic hood of *Gasteropteron*, the "oral" tentacles of *Aplysia*, the hood of *Tethys*, the "lips" of some Pteropoda, and the hood of *Pneumodermon* may be the result of a similar change. But all attempts to settle these points, save by development, must be more or less hypothetical*.

To this same test of development we must refer everything which claims to be called "*mantle*," a word which has perhaps been more vaguely and loosely used than any other term in zoology. Surely if a term is to have any value in either zoological or anatomical nomenclature it must be applied to only a defined thing. The "mantles" of a *Sepia*, a *Cleodora*, or a *Buccinum* may be homologous with one another, but they certainly are not so with what is called the "mantle" in *Doris* or any other Nudibranch†. The simple fact that the cephalic tentacles arise in the midst of the

is never permanently developed, and the position of the alæ would lead to the belief that they correspond to its lateral portions[1].

So far as I can judge from the Latin table affixed to his Swedish essay on the development of the Acephala, Lovén considers the arms of the Cephalopoda, the three pairs of cephalic tentacles of *Clio*, and the cephalic lobes of *Tethys*, to be homologous with the velum of the Gasteropod embryo, while the funnel of Cephalopoda and the alæ of Pteropoda are homologous with the foot of Gasteropoda.

The considerations above cited appear to me to furnish a sufficient refutation of these views, which seem to be the offspring of an idea first propounded by their learned author in his "Contributions to the Embryology of the Mollusks" (Oken's Isis, 1842), that the hood of *Tethys* and the cephalic processes of *Tergipes* are modifications of the cephalic vela of the embryo. This ingenious hypothesis has not however been confirmed by observation so far as regards *Tethys*, and has been directly *dis*proved with respect to *Tergipes* (see Schulze, Ueber die Entwickelung d. *Tergipes lacinulatus*, Wiegmann's Arch. 1849).

* In the absence of any knowledge of development perhaps the source of the nervous supply is one of the best tests of the real homology of a part. Mr. Hancock, in his valuable paper "Upon the Olfactory Apparatus in the *Bullidæ*" (Annals of Nat. Hist. March 1852), has, I observe, applied this test to the cephalic expansion of the *Bullidæ*, to the hood of *Gasteropteron*, &c.; and since it clearly appears that these parts are supplied by nerves from the *cephalic* ganglia, which never give branches to any portion of the foot, the suggestion in the text must be given up.

† Leuckart, believing the hæmal tegument of the Nudibranchiata to represent a mantle, suggests that there

[1] The researches of Vogt, already referred to, have fully confirmed this conclusion. The embryo Pteropod has vela, which eventually disappear, while the epipodia are developed quite distinctly from the upper part of the sides of the "foot."

so-called "mantle" of the latter, is sufficient evidence to show that it cannot be homologous with the "mantle" of the former. The so-called "margins of the cloak" in these genera appear to me to have much more relation to the epipodium.

Cuvier allows a mantle to *Doris*, but denies it to *Glaucus* and *Eolidia*; why, is not obvious.

Leuckart defines a mantle to be "a scutellate (schildförmig) duplicature of the outer integument extending from the neck for a varying distance backwards." By this definition however the upper surface of the anterior division of a *Bulla* would be a "mantle," which it is not, since the true mantle is obviously behind separated from this by a deep cleft, and how would the mantle of *Firola* or *Carinaroides* answer the definition?

If the definition which I have given of the true "mantle" be correct, we must, I think, hesitate for the present in conferring that name upon the dorsal shell-bearing integument of *Chiton*. May this not be homologous with the thick-edged dorsal surface of a *Doris*, in which the calcareous particles instead of being scattered are united into distinct plates*?

With regard to the shells, again, at the risk of being blamed for over-refinement, I would suggest, that it is, to say the least, an open question, whether the shell of *Buccinum* is (as it is commonly supposed to be) homologous with that of *Helix*; that of *Sepia* with that of *Nautilus* and *Ammonites*; that of the embryo *Aplysia* with that of the adult *Aplysia*. Grave differences of development occur in some if not in all of these cases†.

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is a difference between their "gills" and those of other Mollusks, which, as he justly observes, are never processes of the mantle, *loc. cit.* p. 130. The argument in the text tends to show, that in this respect there is in reality no difference between the "gills" of the Nudibranchiata and those of other Mollusks. On other grounds however I am inclined to think that Leuckart's distinction is a just one. The organs called gills in the Nudibranchiata appear to me to be in all cases what they undoubtedly are in *Eolis*, viz. gastro-hepatic appendages. Even in *Doris*, where they are gill-like, they are supplied with hepatic blood only. See Hancock and Embleton's admirable memoir "On the Anatomy of *Doris*," Philosophical Transactions, 1852.

* In D'Orbigny's genus *Villiersia*, allied to *Doris*, the calcareous tegumentary particles of the *Doridæ* have united into a flat shell, hidden in the "mantle," which is pierced by the apertures for the tentacles and gills. The disposition of the calcareous particles in the *Doridæ* is very regular, though it seems too much to assume with Lovén that they imitate a subspiral shell (see Lovén, Oken's Isis, 1842).

† The memoir by Dr. Gegenbaur, "Beiträge zur Entwickelungsgeschichte der Land Gasteropoden," which has just appeared in Siebold and Kölliker's "Zeitschrift für Wissenschaftliche Zoologie," furnishes very powerful support to the doubts above suggested, since it demonstrates that the shell of *Clausilia*, and gives good reason for believing that that of *Helix*, are developed within the substance of the mantle, following exactly the type of *Limax*.

"The land Gasteropoda are distinguished by the peculiar mode of development of their shell, if we may draw conclusions for the whole group from *Helix* and *Clausilia*. The original deposition of the shell in the interior of the mantle (as in the *Loligidæ* among the Cephalopoda) is as yet an isolated fact among the land Gasteropoda, of which we find no indication in other Gasteropods."

There seems to be a very curious relation between the internal or external nature of a shell, the curvature of its whorls as regards a vertical plane, and the hæmal or dorsal flexure of the intestine.

Take, first, the case of a true external shell, as that of *Nautilus* or *Argonauta*, or *Atlanta*. Here the direction

From all that has been stated, I think that it is now possible to form a notion of the archetype of the Cephalous Mollusca, and I beg it to be understood that in using this term, I make no reference to any real or imaginary "ideas" upon which animal forms are modelled. All that I mean is the conception of a form embodying the most general propositions that can be affirmed respecting the Cephalous Mollusca, standing in the same relation to them as the diagram to a geometrical theorem, and like it at once imaginary and true.

The archetype of the Cephalous Mollusca, then, it may be said, has a bilaterally symmetrical head and body. The latter possesses on its neural surface a peculiar locomotive appendage, the foot; which consists of three portions from before backwards, viz. the propodium, the mesopodium and the metapodium, and bears upon its lateral surface a peculiar expansion, the epipodium (Plate V. fig. 1).

The hæmal surface of the archetype may or may not secrete a shell upon its surface, or in its interior.

If we compare this unmodified form with the vertebrate or articulate archetype, we find that the three essentially correspond. The appendicular system of the Vertebrata and Articulata is represented by the epipodium in the Cephalous Mollusca (Plate V. figs. 9, 10, 11).

Nevertheless the differences between the three archetypes are so sharp and marked, as to allow of no real transition between them.

In the Cephalous Mollusca *it is the hæmal side of the body which is first developed.* In the Articulata and Vertebrata it is the *neural side which first makes its appearance.*

The archetype of the Cephalous Mollusca further differs from that of the Vertebrata (and resembles that of the Articulata), in the circumstance, that while in the latter the nervous and intestinal axes are parallel, in the former they decussate; that is, the œsophagus opens on the neural side, passing between the great nervous commissures.

The molluscous archetype again differs from that of both Vertebrata and Articulata in its appendicular system (*ep*), which, when it exists, never presents articulations nor anything that can be called an external or internal skeleton (unless indeed the funnel-cartilages of Cephalopoda be such), and which is generally altogether suppressed in the adult state, its place being supplied by the foot, which, as a development of the central neural region into a locomotive organ, is, so far as I am aware, paralleled throughout the Vertebrata and Articulata by nothing but the dorsal fin of a fish.

In the actual forms, the symmetry of the archetype is almost always disturbed by

in which the shell is wound is the same as that in which the intestine is bent. While the aperture of the shell therefore is "hæmad" in *Atlanta* with regard to the axis of columella, it is "neurad" in *Nautilus* and *Argonauta*.

With an internal shell the reverse appears to be the law. Hence the curvature of the shell of *Spirula* is the opposite of that of the shell of *Nautilus*, and that of a pulmonated Gasteropod is the same as that of a Pectinibranch.

the excessive development of a peculiar region of the hæmal surface, into what has been termed the abdomen or post-abdomen, according as it is placed before or behind the anus.

The integument of this outgrowth, commonly modified in structure and having frequently a prolonged anterior or posterior margin, is the "mantle." It may or may not secrete a shell.

The development of an abdomen (Plate V. figs. 2, 3, 4, 5) produces a corresponding *neural* flexure of the intestine, as in Cephalopoda, Pteropoda and Pulmonata; that of a post-abdomen produces a *hæmal* flexure, as in Heteropoda, Pectinibranchiata, Tectibranchiata and Nudibranchiata (Plate V. figs. 6, 7, 8).

From combinations of these primary changes with subsequent greater or less developments of the various parts of the foot, all the varieties of form in the Cephalous Mollusca are produced*.

The formation of an abdomen with a peculiar development of the margins of the foot into elongated processes, and with cohesion of the posterior epipodial lobes, gives us the Cephalopodan subtype.

The formation of an abdomen with an excessive development of the epipodium, at the expense of the foot-proper, characterizes the Pteropoda.

The formation of an abdomen with a moderate development of the foot-proper, and hardly any of the epipodium, marks the Pulmonate subtype.

The Heteropoda combine a great development of the foot-proper with the formation of a post-abdomen (and only a transitory development of the epipodium?). The Pectinibranchiata seem to differ from them only in degree.

The development of a post-abdomen, coexistent with that of the epipodium, characterizes the Tectibranchiata.

The Nudibranchiata have a post-abdomen and an epipodium in their embryonic condition, but lose both (epipodium?) more or less completely as they attain maturity. The foot-proper is very moderately developed, or even disappears (*Phyllirrhoë*).

If the "mantle" is to have an analogue anywhere among the Articulata or Vertebrata, it may probably be with the carapace of the Crustacea, inasmuch as this is developed from a corresponding region and has similar functions, *i. e.* to protect the respiratory organs.

Hitherto what has been said has referred to the morphology of the external organs. It remains to show on what plan the internal organs are arranged, and how the archetypal arrangement is modified among the different families. To enter upon this subject fully would belong rather to a formal treatise upon the Mollusca. For the present my object is merely to point out the fundamental unity which obtains

* For clearness' sake I have referred to the "hæmal" and "neural" flexures as if they always took place in a vertical plane, whereas, as every one knows, the anal aperture is almost always either to the right or the left in the Gasteropoda. The only modification of the theory required to meet this fact, is to suppose that the hæmal outgrowth takes place more rapidly on one side than on the other.

among certain of the most important systems of organs, and to bring into prominence some facts in the anatomy of the Mollusca which have hitherto been unknown or neglected.

With these views I propose to treat—1, of the nervous system; 2, of the vascular system; 3, of certain portions of the alimentary system; and 4, of the renal system.

1. *Nervous System.*—The nervous system of every Mollusk consists of two great systems;—A. an excito-motor, or sensory and volitional system; B. a visceral or sympathetic system. The former consists of three pairs of primary ganglia, which always exist, and of a variable number of accessory local ganglia, which may or may not exist*.

* The first record I can find of the distinct enunciation of this very important anatomical fact, is in M. Souleyet's essay on the Pteropoda (Observations Anatomiques, Physiologiques et Zoologiques sur les Mollusques Ptéropodes), of which an abstract is given in the Comptes Rendus for 1843: he says,—"The central nervous system of the Mollusca is essentially composed of the three orders of ganglia which I have just pointed out (orders answering exactly to those mentioned in the text), and it is in fact reduced to these ganglia in a certain number of animals of this type. But in others the nerves which are given off present numerous enlargements in their course, and this tendency to a ganglionic disposition is so decided among the highest Mollusks, that all the nerves emanating from the central medullary masses produce new ganglia in the parts to which they are distributed" (p. 667).

Again:—"From the facts which have just been stated summarily, I believe I may conclude,—

"1. That the exclusive analogy which many naturalists have wished to establish between the nervous system of the Mollusca, and one of the portions of the same system in the animals of higher classes, is not only contrary to physiological principles, but also to anatomical facts.

"2. That the nervous system of Mollusks corresponds, in fact, in its distribution to the same parts as those which constitute it in the superior animals, the whole difference consisting in the degree of development and disposition of the parts which is in relation with the rank that Mollusks occupy in the series, and the plan which nature has followed in their zoological type.

"3. That the definition very commonly given of this system in Mollusks, that it is *composed of ganglia scattered in different parts of the body*, is not exact, since the parts which by their fixity ought to be considered as those which essentially constitute it, are always grouped round the œsophagus. The others, in fact, are to be regarded only as different degrees of development of these central portions, which is proved by their degradation or disappearance in proportion as we descend in animals of this series.

"4. That the central nervous system of Mollusca is always double, and consequently symmetrical, in opposition to what some anatomists have advanced; that it hardly differs in this respect from the nervous system of the Articulata, except by the centralization of the locomotive ganglia, a centralization which may be observed in many animals of the latter type.

"5. Lastly, that it has been wrongly asserted as a general rule, that the ganglia of which the nervous circle of the Mollusca is composed, tend to approximate the higher the organization of the animal, the position of these ganglia being essentially subordinate to that of the organs which they have to innervate" (p. 669).

The very just and admirable views here set forth seem to have met with strange neglect; foreigners, however, might be pardoned for this, since M. Souleyet's own countrymen contrive (see Blanchard, Sur l'organization des Opisthobranchies, Annales des Sc. Nat. 1848) five years afterwards not to know anything about them.

See also the memoir of Hancock and Embleton, before cited, in which the first complete demonstration of the true sympathetic system in the Gasteropoda is given; and Alder and Hancock's British Nudibranchiata, in which are contained the most beautiful descriptions and figures of the anatomy of the Mollusca extant.

These three pairs of primary ganglia are the Cephalic, the Pedal, and the Parieto-splanchnic.

I. *The Cephalic Ganglia.*—These are always either in apposition, or are united by a commissure above the œsophagus. They give off either immediately or from the connecting commissure, the following nerves:—

1. Labial, to the lips and anterior parts of the head.
2. Olfactory, to the tentacles.
3. Optic.
4. Buccal, to the buccal mass, tongue, and jaws.

Accessory ganglia may be developed upon all these nerves. They are found upon the labial nerves in *Gasteropteron*, three upon each side (Souleyet and Blanchard); upon the olfactory nerves in many Nudibranchiata (Alder and Hancock, Souleyet, &c.); upon the optic nerves in Cephalopoda and Heteropoda.

The presence of ganglia upon the buccal nerves is almost constant. There seems to be only one inferior buccal ganglion in some Cephalopoda, while in others there are two, one above and one below. In the Heteropoda, Pteropoda, and most Gasteropoda, there is a pair of ganglia placed laterally at the re-entering angle of the œsophagus and buccal mass. In *Patella*, *Haliotis*, and *Fissurella*, I have found four, two in the latter position, and two anteriorly, just where the buccal nerves come off.

The buccal ganglia are always united by a commissure, so that when the cerebral ganglia are above the œsophagus, an anterior nervous ring is formed; when they are at the side or below, as in Pteropoda, there is no anterior nervous ring.

II. *The Pedal Ganglia.*—These are either in contact or are united by a commissure; *below* the œsophagus they give off—

1. Auditory nerves.
2. Pedal nerves.

The auditory nerves are not commonly present, as their organs are generally sessile; however, they exist in Cephalopoda, and in *Strombus* and *Pteroceras*. As has been stated above, the Heteropoda make an extraordinary exception to the usual position of the auditory organs, since in them these nerves appear to be given off from the cephalic ganglia. Considering, however, that the auditory nerves are invariably attached to the pedal ganglia in all other Mollusks, and that in *Pteroceras* and *Strombus*, genera which so nearly approach the Heteropoda, the auditory nerves are very long, I do not think it very hazardous to suppose, that in the Heteropoda the auditory nerves really proceed from the pedal ganglia, but have become united to the cephalic ganglia.

In any other case their position is quite exceptional, for the supraœsophageal position of the auditory sacs in Nudibranchiatata merely arises from the pedal ganglia being thrust upwards, and united with the cephalic ganglia.

The accessory ganglia of the pedal ganglion appear to be only what may be called

digital ganglia, developed to meet the wants of certain elongations or expansions of the foot.

Such are the ganglia at the bases of the arms of the Cephalopoda, and such appear to me to be the ganglia which supply the "labial" processes of *Nautilus*.

III. Under the name of *Parieto-splanchnic system of ganglia*, I include the branchial and visceral ganglia of most authors, and the cervical, branchio-cardiac, and angeial ganglia of M. Blanchard. This system consists of two *primary* ganglia, which are always to be found at the side of the œsophagus, connected with both the pedal and cephalic ganglia, and for which I reserve specially the term *parieto-splanchnic* ganglia; from these nerves are given off—

1. *Parietal*, to the sides of the body, as distinct from the foot.
2. *Columellar*, to the shell-muscle or muscles, of which there are two in *Octopus*, *Nautilus*, and *Cymbulia*; one in the shelled Gasteropoda.
3. *Branchial*, to the branchiæ.
4. *Angeial*, to the heart and great vessels and generative organs.

Separate ganglia, answering to the three latter sets of nerves, may be found in the dibranchiate Cephalopoda; to the two last in the Heteropoda; a single ganglion corresponding to all of them is found in *Aplysia*, *Buccinum*, *Turbo*, *Paludina*, &c. Two such exist in *Strombus* and *Pteroceras*.

The angeial ganglia, wherever they exist separately, are placed above the aorta and united by a commissure.

The visceral or sympathetic nerves ramify extensively over the intestinal canal (see Hancock and Embleton upon *Doris*). They are connected anteriorly with the buccal ganglia, posteriorly with the parieto-splanchnic system.

To sum up, the typical number of ganglia in the Cephalous Mollusca is three pair, with which accessory ganglia and visceral ganglia may be connected in variable number. The primary ganglia are united by commissures which form—1, two *greater* nervous rings, the *cephalo-pedal*, connecting the cephalic and the pedal ganglia, and the *cephalo-splanchnic*, connecting the cephalic and parieto-splanchnic ganglia: these rings surround both the œsophagus and the aorta. 2, Two *lesser* nervous rings, the cephalo-buccal, uniting the cephalic and buccal ganglia, and encircling the œsophagus, and the parieto-angeial, uniting the parieto-splanchnic and angeial ganglia, and sometimes surrounding the aorta alone: this ring does not seem to be invariably present.

The homology of these ganglia with those of other animals does not, I think, present any very great difficulty.

It is needless to point out their identity with those of the Acephala Lamellibranchiata.

In the Articulata we have corresponding cerebral ganglia, while the subœsophageal ganglionic chain answers to the pedal and parieto-splanchnic ganglia united. The nerves of the latter system appear in a distinct form as the *transverse* nerves of Insects.

It seems possible that the series of lateral ganglia in certain Annelida (*Amphinome*) may correspond with the parieto-splanchnic ganglia of Mollusks.

On the other hand, the stomato-gastric nerves with their ganglia in Articulata appear to correspond with the visceral nerves of Mollusca.

To what portions of the nervous system of the Vertebrata do these various ganglia answer? This is a problem which has been variously solved. Unless, with Von Baer, we deny the homology of the centres of the nervous system in the Invertebrata with those of the Vertebrata, an argument whose worth can only be decided by a careful and laborious study of development, it would seem clear that the cerebral ganglia are homologous with the corpora striata and thalami of Vertebrata. Their accessories, the buccal ganglia, answer to the trigeminal ganglia, and supply similar parts.

The cephalo-pedal and cephalo-splanchnic commissures correspond with the crura cerebri; the pedal and parieto-splanchnic ganglia answering to the spinal cord and medulla oblongata. The origin of the auditory nerves would then correspond with that of the seventh pair in Vertebrata, and the pedal nerves with the spinal nerves in function and position.

Again, if the parieto-splanchnic ganglia represent the medulla oblongata, their branches should, as I think they do, represent a pneumogastric nerve*.

Finally, the visceral nerves answer to the sympathetic.

The next question to be considered is, in what manner these typical ganglia are arranged and combined to form the almost infinite varieties in the actual nervous systems of the Cephalous Mollusca.

We find—

1. The ganglia concentrated into a mass above the œsophagus, e. g. *Doris*, *Phyllirrhoë*, the majority of the Nudibranchiata.

2. The ganglia concentrated into a mass below the œsophagus, e. g. Pteropoda.

3. The ganglia concentrated around the œsophagus, some above and some below, e. g. *Buccinum*, *Helix*, *Onchidium*, Cephalopoda.

4. The ganglia scattered and separated in pairs, e. g. Heteropoda, Tectibranchiata, and many Pectinibranchiata.

Among these the parieto-splanchnic ganglia may either be united by apposition with the pedal ganglia, and with the cerebral by commissure, as occurs most commonly, e. g. *Octopus*, *Nautilus*, *Haliotis*; or they may be united with the cerebral ganglia by apposition, and with the pedal by commissure, as in *Strombus* and *Pteroceras*.

Patella, *Aplysia* and *Bullæa*, form a gradual transition from one of these conditions to the other.

It will be seen at once from this enumeration that the concentration of the nervous

* Von Siebold compares the nerves which arise between the nerves to the ganglion stellatum in Cephalopoda to a par vagum. Vergl. Anat. p. 379.

system is by no means a test of high organization in the Mollusca, but rather the reverse.

A peculiarity of the Mollusks belonging to the second and third categories, viz. that their infraœsophageal nervous mass is often perforated by the aorta, may be accounted for by the narrowness of the angeial ring, consequent upon the concentration of the elements of the parieto-splanchnic system, so that they unite directly above the aorta.

The singular variation in the arrangement of the different portions of the nervous system, whereby the Mollusca as a class differ so widely from the other great classes of Vertebrata and Articulata, may, I think, find an explanation in the well-known law, that the constancy of a given arrangement of organs greatly depends upon the period at which they appear in embryonic life. If certain organs are formed early, those which come later must obviously accommodate themselves to their predecessors; and any variations which have taken place in the latter will perturb the normal disposition of the former.

Now in the Mollusca, as has been already stated, the neural side of the embryo is the last to be developed, and the nervous system does not make its appearance until the animal has taken its characteristic form.

Contrast this with the Vertebrata; in them the nervous system is the first to be developed, and it is, of consequence, the most fixed and unchanging feature in the whole of their organization.

On the other hand, the separation of the abdomen or post-abdomen from the body is one of the earliest facts in molluscous development, and it has a corresponding influence over their whole organization.

The Archetypal Vascular System and its modifications.—It may be questioned whether the "archetypal" heart has a single or a double auricle, but it is certain that in proportion as the symmetry of the branchial apparatus and of the whole body is preserved, we approach to the form of heart with a double auricle. Thus we have a double auricle in *Chiton* and *Haliotis*, and a close approach to it in *Tethys*, *Janus*, and the *Eolidæ*.

In the Cephalopoda the contraction of the branchio-cardiac veins has been observed by Milne-Edwards and Kölliker, so that they may be considered to be auricles. This is another curious illustration of the fact, that what is commonly considered the most concentrated and highest organization does not occur in the reputed highest forms of Mollusca.

The heart lies above the intestine, and gives off the aorta anteriorly. This runs forwards through the cephalo-pedal ring with the œsophagus, and terminates eventually in the buccal mass. Its main branches may be classed as visceral and pedal.

It is needless to enter here upon the beautiful discoveries of M. Milne-Edwards, with respect to the incompleteness of the circulation in the Mollusca. The facts I

have detailed add ocular proof to his already convincing demonstrations. But it is to be observed, that in this respect, again, the "highest" Cephalopod, *Octopus*, possesses no "higher" organization than the Slug or Snail*

The consideration of the archetypal vascular system leads naturally to that of the value of the distinction made by M. Milne-Edwards between *opisthobranchiate* and *prosobranchiate* Mollusca. If my views be well-founded, it is clear that opisthobranchism is the typical condition of all Mollusks, and that prosobranchism is one result of that asymmetrical development which I have endeavoured to show to be the principal agent in modifying the form of these animals. A little consideration will render it evident, that neither the *neural* nor the *hæmal* flexure will have any effect in altering the position of the heart, so long as the flexure occurs *behind* it, while either flexure will produce prosobranchism, if it take place *before* the heart.

Prosobranchism then indicates that a flexure has taken place, but not in what direction; opisthobranchism indicates only that no flexure has taken place in front of the heart.

As derived characters, therefore, we may expect them to fail in certain cases; and those Mollusks which I have chosen to illustrate this paper are instances of their failure. *Firoloïdes* is nearly opisthobranchiate, while *Atlanta* is very decidedly prosobranchiate; and similar variations, as I have shown, occur among the Pteropoda.

The Archetypal Alimentary Canal consists of—1, lips; 2, jaws; 3, buccal mass and tongue; 4, œsophagus; 5, crop; 6, stomach or gizzard; 7, pyloric appendage; 8, intestine; 9, glandular appendages. I wish here merely to draw attention to some peculiarities of the third and the seventh organs in this list, which have not, I think, been hitherto sufficiently noted.

Of the Structure of the Buccal mass and Tongue (Plate V. figs. 12, 13, 14, 15).—Although the structure of the "tongue" of the Mollusca has been very elaborately investigated, its mechanism appears to me to have been hardly at all understood.

Cuvier, who first described this structure in *Buccinum*, thought that the buccal cartilages were the chief agents in moving the tongue. He considered the 'tongue-plate' to be passive, and that its movements depended upon the protraction, retraction, divergence or approximation of the cartilages†.

This idea is still further carried out in the Leçons d'Anatomie Comparée (2nd ed. t. v. p. 15–25), where the cartilages are compared to rudimentary jaws, though a little consideration would have shown the jaws to be represented by other organs in some of the instances quoted.

Subsequent writers either coincide in Cuvier's view, or substitute for it some vague notion of licking or rasping; so Osler‡ and Troschel§.

* The "vena cava superior" of Cephalopoda answers to the very short trunk formed by the union of the two afferent branchial trunks in *Aplysia*, &c., which, as receiving the veins of the foot, correspond with the venous circlet at the base of the arms.

† Mém. sur les Mollusques, Grand Buccin, p. 9.

‡ Philosophical Transactions, 1832.

§ Wiegm. Arch. 1836.

Middendorf, in his elaborate Monograph upon *Chiton* (Malacozoologia Rossica), gives a very careful and detailed description of the buccal apparatus in that Mollusk, but equally fails in rendering its action clear.

He gives the name of tongue exclusively to a "bifid papillose organ, surrounded by circular folds, which consists mostly of vascular branches, between which masses of muscle are interwoven:" this is placed in the floor of the buccal cavity in front of, and below the buccal mass.

To what is commonly known as the tongue, he gives the name of "radula," "reibplatte." The dentigerous plate is the "lamina radulæ," its expanded portion the "orbis radulæ." What I have called the buccal cartilages are his "folliculi motores."

It is difficult to come at any clear understanding of Middendorf's views, but so far as I can comprehend them, he appears to consider that the "lamina radulæ" acts as a sort of elastic file pushed from behind by a special muscle, the "curvator radulæ," and supported and steadied by the "folliculi motores."

Von Siebold says*, "this organ (the tongue), by its protrusion and retraction, is made use of by the Cephalophora as an ingestive apparatus." He says nothing about the buccal cartilages or the minute structure of the organ.

When I first examined this apparatus carefully six or seven years ago in *Buccinum*, I was convinced that Cuvier had mistaken its mode of operation, and further observation has only strengthened that conviction.

I have already described the manner in which the apparatus may be *seen* working in *Firoloïdes* and *Atlanta*, and I propose now to demonstrate that from the anatomical arrangements the "tongue" has the same chain saw-like mode of operation throughout the Cephalopoda and Gasteropoda. Perhaps *Patella* may be taken as the most convenient illustration, since the organ is here very large, and its parts are distinct and well-developed.

In *Patella* (Plate V. figs, 12, 13) it is an oblong mass, reddish, except where the tongue-plate shines with a somewhat greenish hue. It is bifid posteriorly, and has a sulcus along two-thirds of its upper surface. In this the tongue lies before it enters the cavity of the mouth. The opening of the œsophagus corresponds with about the anterior fourth of the upper surface of the buccal mass.

To the postero-lateral angles of the mass its extrinsic protractor muscles are attached, two on each side. They go to be inserted into the cephalic parietes, two in front of and above, and two behind the supraœsophageal ganglia. The lower ones are united so as to form a broad muscular plate. Two small muscular bands are also sent from the anterior angles of the buccal mass to the skin of the head.

When the muscular expansion formed by the lower protractors is removed, four or five muscular bands (fig. 12 μ) are perceived inserted by their posterior extremities into the posterior and lower part of the "buccal cartilages," and converging anteriorly to be inserted into the lower edge of an "elastic plate."

* Vergleichende Anatomie, p. 320.

From the same point of origin a thick bundle of reddish fibres passes up over the posterior extremity of the cartilages, and is inserted into the upper edge and sides of the "elastic plate." These may be called the intrinsic muscles (fig. 13 μ).

This elastic plate (η) is an elastic transparent membrane, broad posteriorly, and narrower anteriorly, so as to be somewhat heart-shaped. By its superior surface it gives attachment to the "dentigerous plate" (lamina radulæ of Midd.), on which the teeth are set; inferiorly it is very smooth, and plays over the equally smooth pulley-like surface afforded by the larger *buccal cartilages* (fig. 14). These are four in number, two large and two small accessory ones (δ). The larger are elongated, white, cartilaginous-looking plates, excavated internally, and thick and convex behind; their inner edges are kept together by strong transverse muscular fibres. Their upper edges are in contact, forming the smooth surface mentioned above; the smaller seem to be in a manner sesamoid cartilages; they are connected anteriorly with the tongue-plate and posteriorly with muscular fibres, which are inserted into the larger cartilages.

It is clear that the action of the intrinsic muscular bands (having the insertions described) must be to cause the "elastic plate," and with it the "dentigerous plate," to traverse over the ends of the cartilages, just like a band over its pulley, the cartilages themselves being entirely passive in the matter. The extrinsic bands, again, must serve to protract the whole mass and thrust it more or less firmly against the object to be acted upon.

I have examined *Buccinum*, *Fissurella*, *Doris**, *Aplysia*, *Bullæa*, *Helix*, *Onchidium*, *Cypræa*, *Pteroceras*, *Sigaretus* and *Vermetus*, and in all I have found a structure essentially similar to that here described; the difference consisting in the greater or less length of the dentigerous plate, and the more or less complete development and isolation of the buccal cartilages. These are the less distinct the more the tongue becomes a mere organ of deglutition. *Aplysia* and *Bullæa*, for instance, have the cartilages united and much softer than in most genera. The structure of the Cephalopod tongue closely resembles that of *Aplysia*; and it has the further peculiarity, that the portion of the floor of the buccal cavity in front of the tongue (true tongue of Middendorf), which is plicated and distinct in most Gasteropods†, is in the Cephalopods raised up into a laminated caruncle (or several) larger than the tongue itself‡.

This pulley-like structure of the tongue appears to me to be very characteristic of

* See also the description of the "tongue" in this genus by Messrs. Hancock and Embleton, *loc. cit.* p. 210.

† Oeler, *loc. cit.*, p. 505, describes a soft striated papilla arising from the floor of the mouth in front of the tongue in *Patella*, which, he says, "is probably the organ of taste."

‡ See Owen, Article 'Cephalopoda,' Cyc. Anat. and Phys. Is the "horny striated substance" supporting the lingual teeth, "which appears to represent the body of an os hyoides" in *Nautilus*, the representative of the buccal cartilages?

the portion of the molluscous type here considered*, and indeed to be peculiar to it. Its occurrence in *Chiton*, therefore, would effectually determine the molluscous nature of that genus, even if there were no other grounds for the conclusion; while the structure of the buccal armature of *Sagitta*, which has been compared to the protruded tongue of a Heteropod, is in fact so totally different as at once to remove it from the Mollusca†.

I may further remark, that the structure of the tongue in the Cephalopoda adds one more link to the very strong chain of affinity between them and the ordinary Mollusca.

Of the Pyloric Sac.—This appears in various forms in a great number of the Mollusca, and seems to be always in special relation with the liver. In *Atlanta*, it has been seen that its glandular parietes form the liver. In the Cephalopoda the hepatic ducts enter its representative, the spiral sac of *Octopoda*, the elongated sac of *Loligo*. The extreme length of the pyloric sac in *Cleodora*, and the occurrence of a second smaller one, appear to be leading the way to the ramified prolongations of the intestinal canal found in the *Eolidæ*.

In *Pteroceras* a very remarkable structure exists, which, so far as I am aware, has not yet been noticed‡. The existence of a "crystalline style" in connexion with the alimentary canal, has long been known in the Lamellibranchiata, but it has hitherto been supposed to be confined to them. However, in *Pteroceras*, the pyloric sac contains a very complete style, Plate V. figs. 16, 17.

The stomach is a wide somewhat quadrangular cavity. The œsophagus opens into

* It has been noticed by Troschel (Anatomie von *Ampullaria Urceus*, Wiegm. Arch. 1845), that the structure of the tongue is the same throughout those Mollusks which have a head: "Under the jaw lies the anterior part of the so-called tongue, a membrane which is present in all Pteropoda, Cephalopoda, Gasteropoda, in short, in all those Mollusks which possess a head. It is wanting in all the so-called Acephala, in the Bivalves and in the Tunicata. It rests, as in all cases where it is present, upon two portions of cartilage of whitish colour, combined by a membrane and moved by many muscles." It is clear, however, from this passage, that Troschel has not recognized the true mechanism of the organ.

† There is a curious similarity between the "tongue" of the Mollusca and the arrangement of the dental apparatus in the Plagiostome fishes, which may be viewed perhaps as another illustration of Von Baer's law, that while the exterior of a vertebrate animal is Articulate in its construction, the interior is Molluscous.

‡ Since writing the above, I find that so far back as 1829, the existence of this organ was distinctly pointed out, though strangely enough the fact has been quite overlooked by every one save Von Siebold; he, however, merely refers to the statement in a note, and says he "does not know what to make of it." (Vergleichende Anatomie, p. 312.) This statement is contained in a valuable paper upon the anatomy of the Mollusca, entitled "General Observations on Univalves," by Mr. Charles Collier, Staff-Surgeon at Ceylon; printed in the Edinburgh New Philosophical Journal for 1829, p. 231. "There is an organ, the crystalline stiletto, confined erroneously by a celebrated naturalist (Cuvier) to bivalves, which is found in every species of *Strombus*, in *Trochus turritus*, and a species (*Vertagus*) of *Murex*. It is enclosed in a sheath, that passes parallel to and by the side of the œsophagus, to the stomach, into which the stiletto enters, leaving its covering; that end which lies within the stomach is obtuse, laminated, and fixed by a hook of similar substance to its situation. The upper portion is circular, homogeneous, slightly tapering, transparent, of gelatinous consistence, and resembling somewhat a pistil with its stigma."

its left anterior angle, while its pyloric orifice, very close to this, is at the right anterior angle. Behind the pyloric orifice the rounded head of the crystalline style projects from the aperture of the pyloric sac, γ, fig. 16.

Two wide apertures communicate with the liver, and act as hepatic ducts.

Several considerable ridges of the gastric membrane rise from the floor of the stomach; the principal one is next to the cardia, and there is a smaller between the cardia and pylorus. The aperture of the pyloric sac is surrounded by an elevated circular ridge, which is slit towards the pylorus, the left edge of the slit overlapping the right. The end of the style projecting from this orifice is opposed by one or two cartilaginous plates upon the principal elevation. It is only the end of the style which is free; for the rest of its length (2 or 3 inches) it lies in the pyloric sac (λ, fig. 17), which runs back over the intestine, in the thickness of the left side of the mantle, and terminates by a rounded extremity.

It seems probable that the "crystalline style" is secreted by the pyloric sac, and that it acts as a gastric plate, assisting in the comminution of the food, although its transparent and delicate texture would not seem to fit it for the performance of any very important office of this kind.

Its resemblance in position and structure to the crystalline style of *Solen* is sufficiently remarkable.

Renal System.—It has been shown that in the Heteropoda and Pteropoda a "contractile sac" exists, placed so as to be bathed by the blood entering the auricle. It has been hinted that this is a renal organ, and I now proceed to give the reasons for my belief that it is so.

A hollow sacculated organ, with yellowish glandular parietes, surrounds the base of the pulmonary sac in the Pulmonata, and opens by the side of the rectum. The secretion of this organ has been shown to contain uric acid*. No contractions have been observed in it.

In *Fusus*, *Cypræa* and other Pectinibranchiata, an aperture, frequently seated upon a kind of papilla placed at the posterior and upper part of the branchial chamber, leads into a wide cavity, which is in relation above with the pericardium, and on the sides with the rectum and generative duct. In its anterior wall a yellow gland is frequently attached, which consists of large vascular laminæ. I observed no contractions of either the sac or the yellow gland, but my attention was not at the time particularly directed to this point.

Now I think that this sac, with its vascular gland, is exactly comparable in position to the "contractile sac" and to the renal organ of *Pulmonata*, while, on the other hand, it closely resembles the serous chambers with their contained venous appendages, which open into the mantle-chamber of the Cephalopoda.

The venous appendages of the Cephalopoda, however, have been demonstrated to be renal organs by containing secreted uric acid, and they possess the faculty of rhythmical contraction†.

* H. Meckel, Müller's Archiv, 1846.

† Kölliker, Entwickelungsgeschichte d. Cephalopoden.

The chambers of the venous appendages, then, in the Cephalopoda answer to a "contractile sac," in which the secreting power and the contractile faculty have become restricted and localized in a portion of the organ*.

I have here touched mainly upon the less commonly understood portions of the internal anatomy of the Cephalopoda and Gasteropoda, but they clearly tend to strengthen the conclusion to be derived from embryology and the more generally known anatomical facts, viz. that the Cephalopoda and Gasteropoda are morphologically one, are modifications of the same archetypal molluscous form.

On the other hand, I have made no reference to the Acephala, nor is it my intention to go into that part of the subject; but, for the sake of the zoological bearings of the question, I may shortly express my belief, that of the two families of the Acephala, there is abundant evidence, both anatomical and embryological, to show that the one, the Lamellibranchiata†, is modelled upon the archetype of the Cephalous Mollusca.

Such evidence as we possess with regard to the Brachiopoda, however, is purely anatomical, and (though I am aware that a great weight of authority lies upon the other side) yet Mr. HANCOCK's opinion, that they are rather to be considered as allied to the Polyzoa than to the Cephalous Mollusca, seems to be quite as plausible as the more general notion.

Should this highly ingenious suggestion be found by embryology to be correct, the Brachiopoda will have the same relation to the Polyzoa as the simple Ascidians to the compound Ascidians, and will form a parallel group to the former in M. MILNE-EDWARDS's section of "*Molluscoïdes*."

In conclusion, I would observe, that the archetypal Cephalous Mollusk (as thus defined) is, in all its modifications, sharply separated from other archetypes, whatever apparent resemblances or transitions may exist. In all cases these will, I believe, on close examination, be found to be mere cases of analogy, not of affinity.

As CUVIER long ago remarked of the Cephalopoda and Fishes, so we may say of the Cephalous Mollusca in general and other types:—"Whatever BONNET and his followers may say, Nature here leaves a manifest hiatus among her productions." For instance, great as are the apparent resemblances between a Lamellibranch and an Ascidian, they all vanish upon closer examination‡. Neither in its anatomical nor in its embryo-

* A renal organ of similar character has been long since demonstrated in the Lamellibranchiata. (See VON SIEBOLD, Vergl. Anat.)

† The Lamellibranchiata are as truly cephalous as many Pteropoda, and the possession of a distinct head is so much a question of degree as to be a very unfit classificatory character.

‡ I beg that I may not be misunderstood here. While I consider that there is no transition between the Cephalous Mollusca as such, and the Ascidians or Polyzoa, I also fully believe (and so far as the Ascidians are concerned I have endeavoured to demonstrate, Report on the Structure of the Ascidians, already referred to) that the archetype of the Cephalous Mollusca, that of the Ascidians and that of the Polyzoa, are all referable to a common archetype, the archetype of the Mollusca generally. It is one thing to believe that certain natural

logical relations does the branchial sac of an Ascidian correspond with the mantle-cavity of a Lamellibranch.

The nervous system is totally different. The three pairs of ganglia, which exist in all Lamellibranchiata (even the apodal genera), are replaced by one in the Ascidians, which is not homologous (as is commonly asserted) with the branchial ganglion, or intersiphonic ganglion of Lamellibranchiata, but with their pedal ganglion.

The organization of the circulatory system is wholly different. The Ascidians have a cellulose test, not a calcareous shell. The larval conditions are totally distinct.

If, however, all Cephalous Mollusks, *i. e.* all Cephalopoda, Gasteropoda and Lamellibranchiata, be only modifications by excess or defect of the parts of a definite archetype, then, I think, it follows as a necessary consequence, that no anamorphism takes place in this group. There is no progression from a lower to a higher type, but merely a more or less complete evolution of one type.

It may indeed be a matter of very grave consideration whether true anamorphosis ever occurs in the whole animal kingdom. If it do, then the doctrine that every natural group is organized after a definite archetype, a doctrine which seems to me as important for zoology as the theory of definite proportions for chemistry, must be given up.

Description of the Plates.

In all the Plates the same letters refer to the same parts.

a. Anus.
b. Buccal mass.
c. Contractile sac.
d. Subspiral ciliated band.
ep. Epipodium.
f. Salivary gland.
g. Tentacles.
h. Head.
i. Eye or optic nerve.
j. Auditory vesicle or nerve.
k. Stomach.
k'. Pyloric cæcum.
l. Liver.
m. Mantle.
mt. Metapodium.
ms. Mesopodium.
n. Branchiæ.
o. Ovary.
p. Penis.
pp. Propodium.
q. Abdomen.
r. Post-abdomen.
s. Vesicula seminalis.
t. Testis.
u. Auricle.
u'. Venous canal.
v. Ventricle.
w. Aorta.
w'. Recurrent artery.
x. Cerebral ganglia.
y. Pedal ganglia.
y'. Pedal artery.
z. Parieto-splanchnic ganglia.

groups have one definite archetype or primitive form upon which they are all modelled; another, to imagine that there exist any transitional forms between them.

Every one knows that Birds and Fishes are modifications of the one vertebrate archetype; no one believes that there are any transitional forms between Birds and Fishes.

β. Buccal ganglia or nerves.
γ. Crystalline style.
λ. Its sheath.
δ. Accessory cartilages of the buccal mass.
θ. Tongue plate.
η. Elastic plate.
μ. Muscles.

PLATE II.

Fig. 1. *Firoloïdes Desmarestii.* (Magnified.) Male.
Fig. 2. *Firoloïdes Desmarestii.* Female. Posterior extremity from the left side.
Fig. 3. *Firoloïdes Desmarestii.* Female. Posterior extremity from the right side.
Fig. 4. Penis of the male.
Fig. 5. Egg-tube.
Fig. 6. Nervous system, with the termination of the pedal artery at y'.
Fig. 7. Cerebral ganglia from below.
Fig. 8. Right eye and tentacle.

PLATE III. *Atlanta Lesuerii.*

Fig. 1. Animal in its shell (much magnified), from the right side. Male.
Fig. 2. The same from the left side, to show the arrangement of the nervous and vascular systems.
Fig. 3. Post-abdomen, without the shell; more enlarged, from the right side.
Fig. 4. Portion of the mantle-cavity and post-abdomen from the left side, to show the arrangement of the heart and branchiæ.
Fig. 5. Portion of the penis.
Fig. 6. Cerebral ganglia, from the left side.

PLATE IV.

Fig. 1. *Pneumodermon* ——? A young specimen, to show the form of the foot and its relations.
Fig. 2. *Euribia Gaudichaudii* (Eydoux and Souleyet), from behind, placed, not as it swims, but so as to leave its parts in their normal position. This has been done with each of the figures in this Plate, except it be otherwise expressly mentioned.
Fig. 3. The head and foot of *Euribia*, seen from below.
Fig. 4. *Cleodora curvata* (Eydoux and Souleyet), from the neural side.
Fig. 5. The same, from the hæmal side.
Fig. 6. *Cleodora aciculata*, from the right side, without the shell.
Fig. 7. The same. The head and alæ from the neural side.

PLATE V.

The first eleven figures are to be regarded as mere diagrams, illustrative of the archetypal form of the Mollusca and its more important modifications.

The shaded portion is the hæmal surface, the unshaded the neural surface.

Figs. 2 and 3 are supposed to represent the development of an abdomen, and the changes of position thence undergone by the intestine and heart.

Fig. 4 is a diagram of a Pteropod, corresponding with fig. 2.

Fig. 5 is a diagram of a Cephalopod, corresponding with fig. 3; but in these, changes in the different parts of the foot have been also effected.

Figs. 6 and 7, similarly are supposed to represent the development of a post-abdomen.

Fig. 8. A diagram of *Aplysia*, corresponding with fig. 6. *Atlanta* corresponds exactly with fig. 7.

Figs. 9, 10, 11, are imaginary sections of a Mollusk, a Fish and an articulate animal, respectively, to show the relations of the nervous, alimentary, vascular and appendicular systems.

The Mollusk and articulate animal are in their normal position; the fish is turned upon its back to correspond with them. * The pectoral fins. † The legs of the articulate animal.

Figs. 12–15. The buccal apparatus or tongue of *Patella*.

Fig. 12. From the right side.

Fig. 13. From above.

Fig. 14. The supporting cartilages.

Fig. 15. The elastic plate which plays over them.

Figs. 16, 17. The stomach of *Pteroceras*.

III. *On Rubian and its Products of Decomposition.* *By* EDWARD SCHUNCK, *F.R.S.*

Received April 19,—Read June 10, 1852.

PART II.

Action of Alkalies and Alkaline Earths on Rubian.

IN the first part of this paper I have described, in general terms, the effect produced on rubian by alkalies. It is only the fixed alkalies that are capable of effecting the decomposition of rubian. Ammonia produces no perceptible change in a watery solution of this substance, except that of altering its colour from yellow to blood-red. This blood-red colour remains unchanged even after long-continued boiling, and the solution still contains rubian, for on supersaturating the ammonia with acid, the solution again becomes yellow, and not the slightest precipitate is produced. The fixed alkalies, on the other hand, act very differently. On adding caustic soda to a solution of rubian, the colour of the solution first changes to blood-red. On boiling the liquid, however, its colour soon changes again from blood-red to purple. This alteration in colour indicates the formation of alizarine. If the boiling be continued, there is deposited, as the liquid becomes more concentrated, a dark purple powder, which consists mainly of a compound of alizarine and soda, and separates in consequence of its insolubility in caustic lye. After the liquid has been boiled for some time, then, provided the quantity of soda employed be sufficiently large, the rubian is entirely decomposed. On now adding sulphuric acid in excess, a quantity of orange-coloured flocks, exactly like those produced by the action of acids on rubian, is precipitated, while the liquid becomes almost colourless. These flocks are separated by filtration and washed with cold water, until the sulphate of soda and sulphuric acid are entirely removed. They now consist mainly of four substances, viz. 1st, *Alizarine*; 2ndly, *Rubiretine*; 3rdly, *Verantine*; and 4thly, a substance which has not hitherto been observed, and to which I shall give the name of *Rubiadine*.

In order to separate these substances from one another, I adopt almost the same method as that employed for the separation of the products of decomposition with acids. The mixture is first treated with boiling alcohol, which dissolves the greatest part, leaving undissolved however a considerable quantity of a dark brown flocculent substance. This substance invariably accompanies the other products of the action. It is, however, as its properties and composition show, a secondary product of decomposition, the formation of which I shall explain presently. To the dark yellow alcoholic solution, after filtration from this flocculent substance, there is added acetate of alumina, which produces a dark red precipitate. This precipitate,

which is a compound of alizarine and verantine with alumina, is decomposed with muriatic acid, and the alizarine and verantine are separated from one another by means of acetate of copper, and purified in the manner which I have before described, when treating of the products of decomposition with acids. The liquid filtered from this alumina compound is still yellow. On adding to it sulphuric acid and a large quantity of water, the substances dissolved in it are precipitated in the shape of yellow flocks, which after filtration and edulcoration are redissolved in boiling alcohol. On adding acetate of lead to this solution, there is produced a dark purplish-brown precipitate, which consists of rubiretine and verantine in combination with oxide of lead. The liquid still remains yellow, and is filtered from the precipitate. The latter, on being decomposed with boiling muriatic acid, gives a brown powder, which, after filtration and edulcoration, is treated with cold alcohol. This dissolves the rubiretine, leaving behind the greatest part of the verantine. The alcoholic liquid, after filtration and evaporation, leaves a residue of rubiretine with its usual appearance and properties. Should it not melt easily when thrown into boiling water, it must again be treated with a small quantity of cold alcohol, when an additional portion of verantine remains undissolved, and the alcohol on evaporation usually gives pure rubiretine. Should it, however, still contain verantine, the process of treating with cold alcohol must be repeated, until it is free from that substance. The alcoholic liquid filtered from the lead precipitate contains the substance which I call rubiadine. In order to obtain it in a state of purity, water is added to the solution. This produces a yellow precipitate, which after filtration is treated with just sufficient boiling alcohol to dissolve it. To the solution while boiling, there is added hydrated oxide of lead, which takes up the impurity, consisting chiefly of rubiretine, and renders the solution of a lighter yellow. The liquid, after being filtered boiling hot, deposits the rubiadine on cooling in small yellow needles. An additional quantity may be procured by evaporating the mother-liquor, but this portion is not sufficiently pure to assume a crystalline form, and has the appearance of an amorphous yellow powder. By exposing it to heat, however, a crystalline sublimate of rubiadine may be obtained.

The acid liquid filtered from the mixture of the four preceding substances still contains in solution another product of decomposition. After neutralizing the sulphuric acid with carbonate of lead, and evaporating the filtered liquid to dryness, a residue is left, which is treated with alcohol. This leaves undissolved the sulphate of soda, and after filtration and evaporation gives a brown glutinous mass, which has all the properties of the sugar produced by the action of acids on rubian. It is this sugar, which, by the continued action on it of the caustic alkali, gives rise to the formation of the dark brown flocculent substance, insoluble in alcohol, which is found mixed with the four preceding products of decomposition. This fact is sufficiently proved by the composition of the latter substance, which is identical with that of the brown substance produced by the action of strong acids on ordinary sugar.

The products formed by the action of caustic baryta on rubian do not differ from those resulting from the action of caustic soda. On adding caustic baryta to a solution of rubian and boiling for some time, the rubian is entirely decomposed; the decomposition, as might be supposed, requiring a rather longer time for its completion than in the case of caustic soda. After the process is finished, the products of decomposition are found for the most part in combination with baryta in the shape of a purple powder, while the liquor still retains a red colour. The purple powder is placed on a filter and slightly washed with cold water. On passing carbonic acid through the filtered liquid, the latter loses its red colour, and a yellow flocculent substance is precipitated together with carbonate of baryta. The liquid, after being boiled in order to decompose the bicarbonate of baryta, and then filtered, is evaporated over sulphuric acid at the ordinary temperature, when it leaves a substance of a light brown colour, which resembles the sugar produced by the action of acids on rubian, but is not quite so deliquescent. This substance, as I shall presently show, is in fact a baryta compound of sugar. The mixture of yellow flocks and carbonate of baryta is now added to the purple powder before mentioned, and the whole is treated with muriatic acid in order to extract the baryta. The acid leaves undissolved a quantity of orange-coloured flocks, which consist, as before, of alizarine, rubiretine, verantine, and rubiadine, as well as of some of the dark brown flocculent substance, insoluble in boiling alcohol, and are separated from one another in the manner just described. If sulphuric acid be employed instead of carbonic acid for separating the baryta from the red liquid, and the excess of acid be neutralized with carbonate of baryta, the liquid on evaporation gives a substance exactly similar to that obtained in the other case, being also a compound of sugar and baryta, but differing from the latter in containing only half the quantity of baryta. The identity of the alizarine and rubiretine obtained by the action of alkalies, with those produced by the action of acids on rubian, is proved by the following analyses.

0·2255 grm. crystallized alizarine obtained by means of caustic soda, lost on being heated in the water-bath, 0·0405 water = 17·96 per cent.

0·1820 grm. of the dry substance, burnt with chromate of lead*, gave 0·4610 carbonic acid and 0·0770 water.

These numbers correspond in 100 parts to—

Carbon	69·07
Hydrogen	4·70
Oxygen	26·23

I. 0·2610 grm. rubiretine, prepared by means of caustic soda, and dried at 100° C., gave 0·6565 carbonic acid and 0·1250 water.

* In order to avoid repetition, I may state that all the organic analyses given in this paper, in which the material used for combustion is not especially mentioned, were performed with chromate of lead.

II. 0·3630 grm. rubiretine, prepared by means of caustic baryta, gave 0·9130 carbonic acid and 0·1715 water.

These numbers correspond in 100 parts to—

	I.	II.
Carbon	68·60	68·59
Hydrogen	5·32	5·24
Oxygen	26·08	26·17

I did not obtain a sufficient quantity of verantine in a pure state for the purpose of analysis, but the properties of the substance formed by the action of alkalies on rubian corresponded so exactly with those of the verantine produced by the action of acids, as to leave no doubt of their identity.

The compound of sugar and baryta, obtained by the action of baryta on rubian, is similar in appearance to the sugar itself. Its colour is light brown, and when dry it is brittle and transparent like dried gum or varnish. It exhibits no trace of crystalline form. It is more easily reduced to a state of dryness than the sugar itself, and deliquesces much less when exposed to a moist atmosphere than the latter. When its solution is mixed with acetate of lead, the whole of the sugar seems to be precipitated in combination with oxide of lead. On analysing a specimen of this substance prepared by precipitating the excess of baryta with carbonic acid, I obtained the following results:—

I. 0·6375 grm. heated for several hours in the water-bath, gave 0·5245 carbonic acid and 0·1945 water.

II. 0·7575 grm. gave 0·6320 carbonic acid and 0·2235 water.

0·4860 grm. gave 0·3480 sulphate of baryta, equivalent to 0·22838 baryta.

From these numbers may be deduced the following composition:—

	Eqs.		Calculated.	I.	II.
Carbon	12	72	22·20	22·43	22·69
Hydrogen . . .	11	11	3·39	3·39	3·26
Oxygen	11	88	27·14		27·06
Baryta	2	153·2	47·27		46·99
		324·2	100·00		100·00

If the baryta contained in the solution of sugar be precipitated with sulphuric acid, and the latter be again neutralized with carbonate of baryta, there is obtained, as I mentioned above, a compound of sugar and baryta containing less baryta than the preceding. Its analysis yielded the following results:—

I. 0·4330 grm. gave 0·4670 carbonic acid and 0·1825 water.

II. 0·3770 grm. heated for several hours longer at 100° C., gave 0·4150 carbonic acid and 0·1570 water.

0·3890 grm. gave 0·1890 sulphate of baryta, equivalent to 0·1240 baryta.

Hence may be deduced the following composition:—

	Eqs.		Calculated.	I.	II.
Carbon	12	72	30·17	29·41	30·01
Hydrogen . . .	10	10	4·19	4·68	4·62
Oxygen	10	80	33·54		33·49
Baryta	1	76·6	32·10		31·88
		238·6	100·00		100·00

This compound, it will be seen, is identical in composition with the baryta compound of cane sugar. If the formulæ of the two compounds be compared together, it is evident that if both be correct, the one containing most baryta must be written thus,—$C_{12} H_{10} O_{10} + BaO + BaO\,HO$. In this case, however, it would be difficult to conceive how it is possible for the second atom of baryta to escape the action of the carbonic acid used in its preparation. It is therefore more probable that the true formula is $C_{12} H_{10} O_{10} + 2BaO$, which requires in 100 parts—

Carbon	22·84
Hydrogen	3·17
Oxygen	25·39
Baryta	48·60

In fact the amount of carbon and hydrogen found by experiment agree better with these numbers than with those of the other formula.

These analyses lead to the conclusion, that the sugar formed by the decomposition of rubian contains 12, not 14 atoms of carbon. Nevertheless it is doubtful whether in these baryta compounds the sugar exists in the same state as it does when formed by the action of acids on rubian. In the latter state it seems incapable of entering into combination with bases such as baryta or oxide of lead. It is therefore probable that by the continued action on it of alkalies or alkaline earths it undergoes some change, possibly in consequence of the loss of the elements of water.

Among the products of the action of alkalies on rubian, I have mentioned a dark brown substance insoluble in boiling alcohol. This substance is soluble in alkalies with a brown colour, and is reprecipitated by acids. It resembles in all respects the black substances bearing the general name of humus, which are formed by the action of strong acids and alkalies on ordinary sugar. It was analysed with the following result:—

0·3215 grm. gave 0·8040 carbonic acid and 0·1260 water.

In 100 parts therefore it contains—

Carbon	68·20
Hydrogen	4·35
Oxygen	27·45

The ulmic acid of Mulder, obtained by the action of muriatic acid on cane-sugar, contains, according to that chemist (C=6·11),—

Carbon	68·95
Hydrogen	4·23
Oxygen	26·82

The formula given by Mulder for ulmic acid, viz. $C_{40}\,H_{14}\,O_{12}$, requires in 100 parts—

Carbon	68·57
Hydrogen	4·00
Oxygen	27·43

The identity in composition and properties of this acid, and the substance formed by the action of alkalies on rubian, leave no doubt of their being the same.

Rubiadine.—This substance, which has not hitherto been observed among the products derived from madder, bears a close resemblance in its appearance and many of its properties to rubianine, the place of which it in fact occupies in the series of substances produced by the action of alkalies on rubian. Besides its composition, however, there are several properties belonging to it so characteristic, that it cannot be confounded with rubianine or any of the substances previously described. When crystallized from alcohol, it is obtained in the shape of small yellow or orange-coloured needles. A very minute degree of impurity, however, seems to prevent its assuming a crystalline form, in which case it is obtained in small granular masses, or as a yellow amorphous powder. It may be purified by dissolving it in a small quantity of boiling alcohol, and adding to the boiling solution either hydrated oxide of lead, or protoxide of tin. On filtering boiling hot and allowing to cool, it crystallizes out. When heated on platinum foil, it melts and burns with flame. When cautiously heated between two watch-glasses, it may be almost entirely volatilized. On the lower glass a very slight carbonaceous residue is left, while the upper glass is covered with a quantity of partly yellow, partly orange-coloured micaceous scales, endowed with considerable lustre. These scales possess all the properties of rubiadine itself. Rubiadine is insoluble in water. It communicates hardly any colour to boiling water, and the filtered liquid deposits nothing on cooling. It is more soluble in alcohol than rubianine. It dissolves in concentrated sulphuric acid with a dark yellow colour, and is reprecipitated by water in yellow flocks. If the solution in sulphuric acid be boiled, the colour changes to a dark yellowish-brown, a little sulphurous acid is disengaged, and the addition of water now causes a yellowish-brown precipitate. On treating rubiadine with boiling nitric acid, it dissolves, nitrous acid is disengaged, and the liquid on cooling deposits nothing, so that the substance seems to be decomposed by the acid. Towards alkalies rubiadine behaves in a similar manner to rubianine. Ammonia and carbonate of soda change its colour very little in the cold. It is only on boiling the alkaline liquids that it dissolves with a blood-

red colour. It is precipitated from its alkaline solutions by acids in thick yellow flocks. The ammoniacal solution on exposure to the air loses its ammonia and deposits the substance in the shape of a yellow uncrystalline pellicle. On adding chloride of barium to the ammoniacal solution, no effect is produced at first, but after some time a slight dark red precipitate falls. Chloride of calcium, added to the ammoniacal solution, produces almost immediately a copious light red precipitate. Acetate of lead gives no precipitate in an alcoholic solution of rubiadine, and water throws down rubiadine in an uncombined state. On adding acetate of copper to the alcoholic solution, no effect ensues at first beyond a darkening of the solution, but after a few moments a dark brownish-red precipitate falls; the supernatant liquid remains yellow, but contains very little rubiadine in solution. When treated with a boiling solution of perchloride of iron, rubiadine does not dissolve. The liquid changes very slightly in colour, and gives after filtration only a very slight precipitate on the addition of muriatic acid. The residue left undissolved by the perchloride of iron is unchanged rubiadine. By its volatility, when exposed to heat, and by its insolubility in boiling water, rubiadine may be easily distinguished from rubianine, which cannot be strongly heated without decomposition, and is soluble in boiling water.

I only obtained sufficient rubiadine in a state of purity for one analysis, which gave the following results:—

0·2575 grm. gave 0·6725 carbonic acid and 0·1120 water.

These numbers correspond in 100 parts to—

Carbon	71·22
Hydrogen	4·83
Oxygen	23·95

There are several formulæ with which this composition agrees, but only two which at the same time satisfactorily explain the formation of this substance, viz. $C_{28}H_{12}O_8$ and $C_{44}H_{18}O_{11}$. The great similarity in properties between rubiadine and rubianine makes it probable that both have a similar composition, and as it is almost certain from the experiments above detailed that the formula of the sugar resulting from the decomposition of rubian is $C_{12}H_{12}O_{12}$, it follows that the true formula of rubiadine must be one of the two just given.

These formulæ require respectively in 100 parts—

	$C_{28}H_{12}O_8$.	$C_{44}H_{18}O_{11}$.
Carbon . . .	71·64	71·93
Hydrogen . .	4·47	4·08
Oxygen . . .	23·89	23·99

If the first formula be the correct one, then the formation of rubiadine is due to the splitting up of 1 equiv. of rubian, after the assimilation of 2 equivs. of water, into 1 equiv. of rubiadine and 2 equivs. of sugar, as will be seen by the following equation:—

2 equivs. of Sugar . . . $= C_{24}H_{24}O_{24}$
1 equiv. of Rubiadine . . $= C_{28}H_{12}O_8$
$C_{52}H_{36}O_{32}$

$= \begin{cases} C_{56}H_{54}O_{56} = 1 \text{ equiv. of Rubian.} \\ H_4\ O_2 = 2 \text{ equivs. of Water.} \end{cases}$
$C_{56}H_{56}O_{32}$

If the formula of rubianine be $C_{32}H_{19}O_{15}$, rubiadine will differ from it by containing the elements of 7 equivs. of water less. If the formula of rubiadine be $C_{44}H_{18}O_{12}$, then its formation would presuppose the splitting up of 1 equiv. of rubian into 1 equiv. of rubiadine, 1 equiv. of sugar and 7 equivs. of water, for

$$C_{44}H_{32}O_{21}+C_{12}H_{12}O_{12}+7HO=C_{56}H_{44}O_{33}.$$

It appears therefore that the action of alkalies on rubian differs in its results from the action of acids only in one respect, that alkalies as well as acids give rise to the formation of five distinct products of decomposition, that four of these are in both cases perfectly identical, and that the fifth substance produced by the action of acids is replaced in the case of alkalies by another, which, though perfectly distinct, is so similar both in properties and composition, that it may be considered as in every respect its equivalent.

Action of Ferments on Rubian.—It has long been suspected by chemists that the colouring matter of madder owes its formation to some process of fermentation, but the exact nature of the process has hitherto remained unknown. Mr. Higgin first pointed out the fact, that a formation of colouring matter takes place even during the short period occupied in the process of dyeing, and he attributes it to the action of some albuminous substance contained in madder on xanthine. That some process of decomposition takes place on extracting madder with cold or tepid water and exposing the extract to a moderate temperature, is proved by the fact that the extract, if concentrated, becomes after some time thick and gelatinous; and that the process of decomposition takes effect chiefly on the rubian is apparent, since the extract, after it has become gelatinous, is found to have lost its bitter taste and the greater part of its yellow colour.

In order to prepare the peculiar substance contained in madder which has the property of effecting the decomposition of rubian, I proceed in the following manner. A quantity of madder having been placed on a piece of calico or fine canvas, there is poured on it for every pound of madder taken about four quarts of distilled water, which may be either cold or of a temperature of about 38° C. The latter temperature is preferable, as the water then percolates more rapidly. To the extract there is added, without any delay, about an equal volume of alcohol, which causes the separation of a quantity of dark reddish-brown flocks. These flocks are allowed to settle, and the supernatant yellowish-brown liquid is decanted. Fresh alcohol is added to the flocks, which are then placed on a paper filter, and washed on the filter with additional quantities of alcohol, until the percolating liquid, which is at first strongly coloured, becomes almost colourless. This process of washing, which often lasts a long time, may be assisted by removing the mass from the filter and shaking it up with moderately warm alcohol. The substance on the filter has now the appearance of a dark reddish-brown mass, which when rubbed between the fingers produces the same granular feeling as coagulated caseine, the sliminess which characterized it on its first precipitation with alcohol having disappeared. Now this substance possesses

in an eminent degree the power of effecting the decomposition of rubian. If a quantity of it be added to a solution of rubian, and the mixture be left to stand at the ordinary temperature, a complete change is found to have taken place in the course of a few hours. The liquid is converted into a trembling jelly of a light brown colour, which is perfectly tasteless, insoluble in cold water, and so consistent, that if the solution of rubian was tolerably concentrated, the vessel may be reversed without its falling out. It is manifest from this experiment that it is this substance which constitutes the active fermenting principle of madder, and that for the purpose of understanding the nature of the process of fermentation peculiar to madder, it is necessary to examine the action of this substance on rubian. I shall therefore in the first place describe the products resulting from this action, after which I shall return to the consideration of its other properties.

On adding to a watery solution of rubian a quantity of the ferment, prepared in the manner just described, the latter loses its granular nature and diffuses itself in the solution without actually dissolving, forming a muddy, mucilaginous liquid. On allowing this mixture to stand in a moderately warm place, the rubian is gradually decomposed and converted into a brown jelly, similar in appearance and consistency to coagulated blood. Here and there interspersed in the mass yellow streaks and spots, consisting of long hair-like crystals, are sometimes discernible. If, after twenty-four hours, the jelly on being mixed with cold water still yields to the latter any yellow colour, it is a sign that the rubian is not entirely decomposed, and more ferment must be added, the mixture being again allowed to stand until the liquid has become tasteless and colourless. During this process none of the usual signs of fermentation are manifested. The liquid remains perfectly neutral, and no gas of any kind is disengaged. In order however to be perfectly sure of the latter point, I took a solution of rubian in water, mixed it with ferment, poured the mixture into a graduated glass tube, and inverted the latter over mercury. After standing in this way for several days, not a particle of gas had collected at the top of the tube, notwithstanding which the rubian was entirely decomposed, and on examination the products of decomposition were found to be precisely the same as those formed in the usual manner. This experiment proves not only that no gas is evolved during the fermentation of rubian, but also that, as Higgin has observed, the access of atmospheric air is not necessary during the process.

The decomposition of the rubian being completed, a little water is added to the mass, and the gelatinous substance left undissolved by the water is placed on a filter and slightly washed with cold water. The percolating liquid is almost colourless. The gelatinous mass on the filter now consists partly of the ferment employed, and partly of substances formed by the decomposition of the rubian. These substances are six in number, of which three are bodies previously described, and three are new. They are,—1st, *Alizarine*; 2ndly, *Verantine*; 3rdly, *Rubiretine*; 4thly, a substance closely resembling rubiacine, which I shall call *Rubiafine*; 5thly, a substance very

similar to rubianine and rubiadine, to which I shall give the name of *Rubiagine*; and, 6thly, a peculiar fatty substance which I shall denominate *Rubiadipine*. These substances are separated in the following manner. The mixture is treated with boiling alcohol. The alcohol, which assumes a dark reddish-yellow colour, is filtered, and the substance on the filter is treated again with boiling alcohol, until the latter acquires thereby only a light yellow colour. The substance left on the filter consists of the ferment, which has undergone no apparent change either in quantity or properties. To the alcoholic liquid there is now added acetate of alumina, which produces a dull yellowish-red precipitate. This precipitate, which consists of alizarine, verantine and rubiafine in combination with alumina, is separated by filtration and decomposed with boiling muriatic acid, which leaves undissolved a quantity of orange-coloured flocks. The liquid filtered from the alumina precipitate has a dark brownish-red colour. By adding to it sulphuric acid and a large quantity of water, the substances contained in it are precipitated in the shape of a yellow powder. This powder yields nothing to boiling water, which proves the absence of rubianine among the products of decomposition. After being separated by filtration, and washed with water to remove the acid and aluminous salts, it is again dissolved in boiling alcohol, and to the boiling solution there is added an excess of sugar of lead, which causes a dark purple precipitate, the liquid becoming dark yellow. The latter is filtered boiling hot and then mixed with a large quantity of water, which produces a dull orange-coloured precipitate, consisting of rubiagine and rubiadipine in combination with oxide of lead. This precipitate is boiled with sulphuric acid, which turns it yellow; and after the excess of acid has been removed with water, it is treated with boiling alcohol, which leaves undissolved a quantity of sulphate of lead, and acquires a yellow colour. The alcohol on evaporation leaves a residue consisting of rubiagine and rubiadipine. This residue is treated with cold alcohol, in which the rubiadipine dissolves easily, and is obtained on again evaporating as a dark brown, soft, fatty mass. The rubiagine left undissolved is treated with a small quantity of warm alcohol, which removes an additional quantity of rubiadipine, together with a portion of the substance itself, and on redissolving it in boiling alcohol and evaporating spontaneously, it appears in the form of a lemon-yellow mass consisting of small crystalline grains. The dark purple precipitate produced by sugar of lead consists of oxide of lead in combination with rubiretine, alizarine, verantine and rubiafine. It is treated with boiling muriatic acid, which dissolves the oxide of lead. The yellow flocks left by the muriatic acid are, after washing with water, treated with cold alcohol which leaves a part undissolved, and on evaporation gives a residue consisting for the most part of rubiretine. By treating this residue again with cold alcohol, an additional quantity of substance is left undissolved, and the rubiretine is now obtained in a state of greater purity. Its appearance and properties are the same as when obtained by the action of acids or alkalies on rubian. The substance left undissolved by the cold alcohol is added to the orange-coloured flocks proceeding from the

decomposition of the alumina precipitate, and the mixture is dissolved in boiling alcohol. To the alcoholic solution is added acetate of copper, which gives a dirty purple precipitate, consisting of verantine, rubiafine and a portion of the alizarine in combination with oxide of copper, while the liquid, which has a fine purple colour, contains the greatest part of the alizarine. The latter is obtained from this liquid by precipitating with muriatic acid and water, and purified by crystallization. The precipitate produced by acetate of copper is decomposed with muriatic acid, which leaves undissolved a quantity of red flocks. These, after filtration and washing with water, are dissolved in boiling alcohol. Into the boiling solution is introduced a quantity of hydrated protoxide of tin, which thereby acquires a light brown colour, while the liquid becomes light yellow, and on being filtered boiling hot and allowed to cool, deposits the rubiafine in yellow shining plates and needles, which are purified by recrystallization from alcohol. The oxide of tin-lake left on the filter is treated with cold muriatic acid, which dissolves the greatest part of the oxide of tin, and leaves undissolved a dark reddish-brown powder. This is placed on a filter, washed first with muriatic acid, then with water, and then treated with boiling alcohol. The alcohol leaves a great part of it undissolved, and on being filtered boiling hot deposits on cooling a brown powder consisting of verantine. The liquid on evaporation gives a quantity of alizarine, mixed with verantine. The substance left undissolved by the boiling alcohol is dark brown. It is a compound of verantine and oxide of tin, from which I have not been able to extract the oxide of tin by acids or any other means. It is soluble in ammonia and carbonate of soda, and is precipitated unchanged by acids.

The same products as those just mentioned may be obtained from madder by extracting it with cold or tepid water, allowing the extract to stand until a coagulum has been formed in it, placing the coagulum on a calico strainer and then treating it with boiling alcohol. The alcohol leaves undissolved a quantity of ferment, and is found to contain the same substances as those originating from the direct action of the ferment on rubian.

The liquid filtered from the gelatinous mixture of substances insoluble in water, formed by the action of the ferment, still contains in solution a considerable quantity of sugar. On adding to it a small quantity of caustic baryta, a pinkish-white precipitate falls, consisting probably of pectic acid in combination with baryta. The liquid being filtered, the baryta is precipitated with sulphuric acid, the excess of the latter is removed with carbonate of lead, and a small quantity of lead which dissolves is thrown down with sulphuretted hydrogen. The liquid now leaves, on evaporation at the ordinary temperature over sulphuric acid, a brownish-yellow syrup, having the same appearance and properties as the sugar produced by the action of acids on rubian.

The following analyses prove the identity of the alizarine formed by the fermentation of rubian with that derived from other sources:—

I. 0·5210 grm. alizarine, produced by the action of the ferment on rubian, lost, on being heated in the water-bath, 0·0920 water = 17·65 per cent.

0·2500 grm. of the dry substance gave 0·6380 carbonic acid and 0·0960 water.

II. 0·4220 grm., obtained by allowing an extract of madder with tepid water to ferment, lost, on being heated, 0·0750 water = 17·77 per cent.

0·3225 grm. of the dry substance gave 0·8230 carbonic acid and 0·1170 water.

These numbers correspond in 100 parts to—

	I.	II.
Carbon	69·59	69·59
Hydrogen	4·26	4·03
Oxygen	26·15	26·38

The quantity of rubiretine and verantine formed by the fermentation of rubian does not seem to be so large as it is, when acids or alkalies are employed for its decomposition, and as the process of separating and purifying the products of fermentation is, on account of the number of products formed, rather more complicated, the quantity of each substance obtained in a pure state is but small. The following analyses of these two substances were made with specimens obtained by the fermentation of an extract of madder; and even by preparing them in this manner I had some difficulty in procuring a sufficient quantity for examination, because the rubiretine formed by fermentation is always found mixed with rubiadipine, from which it is with difficulty freed; and the verantine is for the most part obtained in combination with oxide of tin, from which I have found it impossible to separate it.

0·3445 grm. rubiretine gave 0·8580 carbonic acid and 0·1695 water.

This gives in 100 parts—

Carbon	67·92
Hydrogen	5·46
Oxygen	26·62

0·3705 grm. verantine gave 0·9010 carbonic acid and 0·1420 water.

In 100 parts—

Carbon	66·32
Hydrogen	4·25
Oxygen	29·43

The great excess of carbon in this analysis indicates an admixture of alizarine. This proceeds from the circumstance that the method of separating verantine and alizarine, by means of acetate of copper, is not absolute. When these two substances are present together in solution, acetate of copper precipitates a portion of the alizarine together with the verantine, and the latter can afterwards only be purified by repeated solution in boiling alcohol, and deposition from the boiling solution.

The compound of verantine and oxide of tin, obtained in the process employed for purifying the rubiafine, cannot, as I mentioned before, be separated into its consti-

tuents. It dissolves in ammonia and carbonate of soda with a dark-brown colour, and is reprecipitated unchanged by acids. Even if it be dissolved in caustic soda, and an excess of sulphuretted hydrogen be passed through the solution, the precipitate afterwards produced by acids yields nothing to boiling alcohol, which proves that the verantine has not thereby been set at liberty. By treating it with boiling alcohol until all the matter soluble in alcohol is removed, then dissolving it in carbonate of soda, filtering from a small quantity of oxide of tin, then reprecipitating with acid, it is obtained in dark brown flocks, which when dry cohere into black, brittle, shining masses. Its analysis now gave the following results:—

I. 0·5930 grm., dried at 100° C., gave 0·6500 carbonic acid and 0·1800 water.

0·3410 grm., heated in a crucible until all the organic matter was destroyed, gave 0·1580 grm. peroxide of tin, equivalent to 0·1411 protoxide of tin.

II. 0·8390 grm. gave 0·9240 carbonic acid and 0·2455 water.

It contains, therefore, in 100 parts—

	I.	II.
Carbon	29·89	30·03
Hydrogen	3·37	3·25
Oxygen	25·36	
Protoxide of tin	41·38	

The formula $C_{56}H_{36}O_{36}+7SnO=4C_{14}H_5O_5+7SnO+16HO$ requires in 100 parts—

Carbon	29·76
Hydrogen	3·18
Oxygen	25·52
Protoxide of tin	41·54

The sugar obtained by the fermentation of rubian does not differ in its properties, as I mentioned before, from that derived from the action of acids on rubian. In composition too it does not materially differ from the latter. I succeeded, however, by exposing it for a considerable length of time to a temperature of 100° C., in depriving it of two atoms more of water, as will be seen by the following analysis:—

0·5540 grm. gave 0·8745 carbonic acid and 0·3055 water.

These numbers correspond with the formula $C_{12}H_{10}O_{10}$, as will be seen by the following calculation:—

	Eqs.		Calculated.	Found.
Carbon	12	72	44·44	43·84
Hydrogen	10	10	6·17	6·23
Oxygen	10	80	49·39	49·93
		162	100·00	100·00

On subjecting it, however, for some time longer to the same temperature, it became very brown, and its analysis now showed that it had absorbed oxygen.

0·5820 grm. now gave 0·8745 carbonic acid and 0·3000 water.

In 100 parts it contained therefore—

Carbon	40·97
Hydrogen	5·72
Oxygen	53·31

On redissolving the remainder in water, it gave a brown solution, but on adding to the solution hydrated oxide of lead, the brown portion was removed, while the solution became almost colourless, and on evaporation over sulphuric acid left a yellow syrup, the composition of which again corresponded with the formula $C_{12}H_{12}O_{12}$, as will be seen by the following analysis:—

0·3710 grm. gave 0·5535 carbonic acid and 0·2135 water.

In 100 parts:—

Carbon	40·68
Hydrogen	6·39
Oxygen	52·93

Rubiafine.—In my former papers on madder I have described a substance which I called rubiacine, and which I prepared partly from madder itself, and partly by the reduction of rubiacic acid with sulphuretted hydrogen. Now rubiafine cannot be distinguished by any of its properties from rubiacine. It crystallizes from its alcoholic solution in yellow glittering plates and needles, which are sometimes arranged in star-shaped or fan-shaped masses. By carefully heating it, it may be volatilized without leaving much residue, forming a yellow sublimate of small shining needles. It is but slightly soluble in boiling water. It is not decomposed by boiling nitric acid or by concentrated sulphuric acid, but merely dissolved by them. It dissolves in caustic alkalies with a reddish-purple, and in carbonated alkalies with a red colour. Its alcoholic solution gives with sugar of lead a fine crimson precipitate, with acetate of copper an orange-coloured precipitate. It dissolves in a solution of pernitrate of iron with a dark brownish-purple colour. The solution, after being boiled for some time, gives, on the addition of muriatic acid, a yellow precipitate, which is rubiacic acid. These properties, it will be seen, belong also to rubiacine. Nevertheless the composition of rubiafine is different, and as I have succeeded in again preparing a substance of the same composition as the rubiacine formerly obtained, they must be considered as distinct bodies.

I am unable to give more than one analysis of rubiafine, which yielded the following numbers:—

0·1765 grm., dried at 100° C., gave 0·4485 carbonic acid and 0·0725 water.

The relation in which rubiafine stands to rubiacic acid proves that the former contains 32 atoms of carbon. Its composition must then be as follows:—

	Eqs.		Calculated.	Found.
Carbon	32	192	69·31	69·30
Hydrogen	13	13	4·69	4·56
Oxygen	9	72	26·00	26·14
		277	100·00	100·00

If this be the true composition of rubiafine, then the latter stands in the same relation to rubian as rubianine and rubiadine, from which, if the latter also contain 32 atoms of carbon, it only differs by the elements of water. If to rubian be added 3 equivs. of water, there are given the elements of 1 equiv. of rubiafine, and 2 equivs. of sugar, for

2 equivs. of Sugar . . .	$=C_{24}H_{24}O_{24}$	$C_{56}H_{24}O_{20}$ = 1 equiv. of Rubian.
1 equiv. of Rubiafine . .	$=C_{32}H_{13}O_{9}$	H_6O_3 = 3 equivs. of Water.
	$C_{56}H_{37}O_{33}$	$C_{56}H_{37}O_{33}$

Rubiacine and Rubiacic Acid.—In my former papers on madder, I have given for rubiacic acid the formula $C_{31}H_8O_{16}$, and for rubiacine $C_{31}H_9O_{16}$. In order to ascertain the correct formula, and also to determine the relation in which they stand to rubian and rubiafine, of which they must be derivatives, I prepared and submitted to analysis a fresh quantity of these substances. For the purpose of preparing rubiacic acid, it is not necessary to take madder itself. If any dyework is at hand in which madder-dyeing is carried on, the liquor in which the goods have been immersed, together with the madder, and which is generally allowed to run to waste, may be employed. This liquid contains a considerable quantity of some substance, which by the action of pernitrate of iron may be converted into rubiacic acid. The mode of operation is as follows. To the liquid, which is brown and muddy, there is added, after the separation of the woody particles of the madder, a quantity of muriatic acid, which gives a brown flocculent precipitate, while the liquid becomes clear and colourless. This precipitate, after being collected on a calico strainer, is treated with pernitrate of iron until nothing more is dissolved. The resulting dark reddish-brown liquid is strained through calico, and acid is added to it, which produces a yellow precipitate. This is filtered, washed and dissolved in boiling carbonate of potash. The solution on cooling deposits crystals of rubiacate of potash, which are placed on a filter and washed with cold water. From a solution of the potash salt, the acid may be precipitated by muriatic or any other strong acid. Some rubiacic acid prepared in this manner was analysed with the following result:—

I. 0·3160 grm. gave 0·7090 carbonic acid and 0·1010 water.

In 100 parts it contained, therefore,—

Carbon	61·19
Hydrogen	3·55
Oxygen	35·26

In my former experiments I obtained as a mean of three determinations the following numbers:—

Carbon	57·28
Hydrogen	2·47
Oxygen	40·25

I was at first unable to explain the great discrepancy here seen, as the new preparation both of the acid and the potash salt had the same appearance as usual. Before proceeding to explain how this discrepancy arose, I may state that the analysis just given corresponds with the formula $C_{84} H_{36} O_{37}$, which requires in 100 parts—

Carbon	61·93
Hydrogen	3·22
Oxygen	34·85

With the same specimen of potash salt as that employed for the preparation of the acid, I made a quantity of silver salt by dissolving the potash salt in water, and adding nitrate of silver. A brilliant cinnabar-red precipitate fell, which was filtered, washed and dried. It was not decomposed either by light or by the heat of boiling water.

0·5800 grm. of this salt, dried in the water-bath, gave 0·9800 carbonic acid and 0·1150 water.

0·3310 grm., treated in a crucible with muriatic acid, and heated until all the organic matter was destroyed, gave 0·1120 chloride of silver.

These numbers lead to the following composition:—

	Eqs.		Calculated.	Found.
Carbon	64	384	46·04	46·08
Hydrogen	18	18	2·15	2·20
Oxygen	25	200	24·00	24·37
Oxide of silver	2	232	27·81	27·35
		834	100·00	100·00

I now took a fresh quantity of waste dye liquor, and divided it into two parts. To the first part I added acid. The precipitate produced by the acid was treated with boiling alcohol, which dissolved a small part with a deep yellow colour, and after being filtered boiling hot and allowed to cool, deposited a quantity of orange-coloured powder. This powder I dissolved again in boiling alcohol, and to the boiling solution I added hydrated protoxide of tin, and filtered boiling hot. The liquid, which had become light yellow, deposited on cooling a quantity of light yellow needles. These needles had the appearance and properties of rubiafine. Their composition, however, proved them to be a distinct substance.

0·1515 grm. gave 0·3730 carbonic acid and 0·0540 water.

In 100 parts, therefore, it consisted of—

Carbon	67·14
Hydrogen	3·96
Oxygen	28·90

To the other part of the liquor I also added acid, and the precipitate, after straining the liquor through calico, and washing with water, I treated with a boiling

solution of pernitrate of iron, which dissolved a portion with a dark purplish-brown colour. Muriatic acid produced in the filtered liquid a yellow precipitate, which after filtering and washing with water, I treated with boiling alcohol. The alcohol being filtered boiling hot, deposited on cooling a yellow powder, which on being redissolved in fresh boiling alcohol, yielded a quantity of yellow shining plates and needles. These corresponded in all their properties with rubiafine and rubiacine. By treatment with pernitrate of iron they were convertible into rubiacic acid.

0·2355 grm. gave 0·5790 carbonic acid and 0·0860 water.

In 100 parts it contained, therefore,—

Carbon	67·05
Hydrogen	4·05
Oxygen	28·90

This analysis proves that the substance contained in the liquor existed in the same state before and after the treatment with pernitrate of iron, and that the latter, in the first instance at least, merely dissolved without changing it. A comparison of the composition of this substance with that of the body which I formerly called rubiacine, proves that they are identical. A specimen of rubiacine obtained on a former occasion from rubiacate of potash by means of sulphuretted hydrogen, I found to contain in 100 parts—

Carbon	67·01
Hydrogen	3·28
Oxygen	29·71

The most probable formula for this substance is $C_{22}H_{11}O_{10}$, which requires in 100 parts

Carbon	67·84
Hydrogen	3·88
Oxygen	28·28

The remainder of the substance I dissolved in boiling alcohol, and added acetate of lead. This gave a dark red precipitate, which after filtering, washing with alcohol, and drying, was found to have the following composition:—

0·5470 grm., dried at 100° C., gave 0·6630 carbonic acid and 0·0890 water.

0·4060 grm. gave 0·2800 sulphate of lead, containing 0·20602 oxide of lead.

These numbers correspond with the formula $3C_{22}H_{11}O_{10}+8PbO$, as the following calculation shows:—

	Eqs.		Calculated.	Found.
Carbon	96	576	33·05	33·05
Hydrogen	33	33	1·89	1·80
Oxygen	30	240	13·78	14·41
Oxide of lead	8	893·6	51·28	50·74
		1742·6	100·00	100·00

The precipitate produced by muriatic acid in the nitrate of iron solution, was not entirely soluble in boiling alcohol. That part left undissolved by the latter I dissolved again in nitrate of iron; I kept the solution boiling for some time, and then precipitated again with muriatic acid. The precipitate, after filtering and washing, I treated with a boiling solution of carbonate of potash, in which it dissolved. On cooling, a considerable quantity of rubiacate of potash crystallized out with its usual appearance. Some of this salt was decomposed with nitric acid, and the rubiacic acid so obtained was analysed.

II. 0·5250 grm. gave 1·1595 carbonic acid and 0·1465 water.

In 100 parts—

Carbon	60·23
Hydrogen	3·10
Oxygen	36·67

These numbers do not differ very widely from those found in the first analysis. On recrystallizing, however, the remainder of the salt from water, and analysing some acid obtained from the recrystallized salt, I obtained the following numbers:—

III. 0·4300 grm. gave 0·9135 carbonic acid and 0·1100 water.

In 100 parts—

Carbon	57·93
Hydrogen	2·84
Oxygen	39·23

With another portion of the recrystallized potash salt I prepared some silver salt, as before. 0·6260 grm. of the silver salt gave 1·0340 carbonic acid and 0·1070 water, corresponding in 100 parts to—

Carbon	45·04
Hydrogen	1·89

The mother-liquor of the salt from which No. III. was made I precipitated with muriatic acid. Part of the precipitate I dissolved again in carbonate of potash, and the acid from the crystallized potash salt showed the following composition:—

IV. 0·4010 grm. gave 0·8690 carbonic acid and 0·1160 water.

In 100 parts—

Carbon	59·10
Hydrogen	3·21
Oxygen	37·69

The remainder of the precipitate I now dissolved again in pernitrate of iron, and after keeping the solution boiling for several hours I precipitated again with muriatic acid, filtered, washed, dissolved the precipitate in carbonate of potash, filtered and precipitated again with muriatic acid. The precipitated rubiacic acid now gave on analysis the following results:—

V. 0·3925 grm. gave 0·8240 carbonic acid and 0·1030 water.

These numbers correspond with the formula $C_{32}H_9O_{17}$, as will be seen by the following calculation:—

	Eqs.		Calculated.	Found.
Carbon	32	192	56·97	57·25
Hydrogen . . .	9	9	2·67	2·91
Oxygen	17	136	40·36	39·84
		337	100·00	100·00

This composition differs, as will be seen, very little from that found in my former experiments.

Some fresh rubiacic acid made in the same manner as that of the last analysis, was dissolved in carbonate of potash, the solution was evaporated to crystallization, the crystallized potash salt was again dissolved in boiling water, and nitrate of silver was added to the solution. The precipitate was now no longer red, but of a dull orange colour.

0·1700 grm. of this precipitate gave 0·2720 carbonic acid and 0·0370 water.

In 100 parts—

Carbon	43·63
Hydrogen	2·40

The formula $C_{32}H_8O_{16}+AgO$ requires in 100 parts—

Carbon	43·24
Hydrogen	1·80

If the formula of the potash salt be similar to that of the silver salt, viz. $C_{32}H_8O_{16}+KO$, it must contain in 100 parts—

Carbon	51·17
Hydrogen	2·13
Oxygen	34·12
Potash	12·58

In my former experiments I obtained as an average of three determinations—

Carbon	51·37
Hydrogen	2·41
Oxygen	33·18
Potash	13·04

It appears therefore that the four first analyses given above were made with impure acid. The analysis No. I. corresponded, as I have shown, with the formula $C_{64}H_{20}O_{37}$. Now if from this formula be deducted that of the pure acid $C_{32}H_9O_{17}$, the difference will be $C_{32}H_{11}O_{16}$, which is the formula given above for rubiacine. It is therefore almost certain that it was an admixture of the latter substance with the acid which raised the amount of carbon and hydrogen in the four first analyses. Whether this impure acid is to be considered as a chemical compound of acid and rubiacine, or whether it contains them in a state of mechanical mixture, is a point not easily deter-

mined. That the acid of the analysis No. I. contained both substances in atomic proportions may be accidental; and the ease with which rubiacate of potash made from the impure acid yields, by mere recrystallization, a salt containing an almost pure acid, tends to prove that the two substances are merely mechanically mingled. Nevertheless it is difficult to detect the presence of rubiacine in the impure acid, which behaves towards almost all reagents in the same manner as the pure acid. The acid of the analysis No. IV., for instance, could not be distinguished from pure acid by its appearance. When treated with boiling alcohol the latter acquired a yellow colour, but on being filtered boiling hot, no rubiacine crystallized out, as would probably have been the case had the latter only been mixed with the acid. Nevertheless, on heating it cautiously between two watch-glasses, a considerable quantity of yellow shining crystals, doubtless of rubiacine, were formed on the upper glass, while the rubiacic acid of analysis No. V. gave, on being heated in the same manner, only a trace of yellow sublimate and an abundant carbonaceous residue. The potash salt of the impure acid has a more granular and less silky appearance than the salt made from pure acid, and is also of a darker red. When heated it does not detonate so strongly as the pure salt. Its solutions give the same reactions as the pure salt with all reagents except nitrate of silver, which, as I mentioned above, gives with the pure salt an orange-coloured, with the impure salt a bright cinnabar-red precipitate.

In order to ascertain whether rubiacic acid is reconvertible not only into rubiacine but also into rubiafine, I took some rubiacate of potash of the same preparation as that employed for the rubiacic acid No. I., dissolved it in boiling water, added caustic soda, and passed sulphuretted hydrogen through the solution for several hours; I then precipitated with chloride of barium, filtered, washed the precipitate, decomposed it with muriatic acid, and crystallized the residue twice from alcohol. The crystals had the appearance of rubiacine or rubiafine, and possessed considerable lustre. On analysis I obtained the following numbers:—

0·1685 grm. gave 0·4340 carbonic acid and 0·0705 water.

In 100 parts it contained therefore—

Carbon	70·24
Hydrogen	4·64
Oxygen	25·12

Though this is not exactly the composition of rubiafine as given above, still it proves that the hydrogen and oxygen are contained in it in the same proportion as in that substance; for if the formula $C_{52}H_{134}O_{84}$, which differs from that of rubiafine by containing $\frac{1}{2}$HO less, be calculated for 100 parts, it gives—

Carbon	70·45
Hydrogen	4·58
Oxygen	24·97

Though I have not, from want of material, been able to trace the steps of the pro-

cess with the requisite accuracy, I think I am justified in inferring from these experiments, that by the oxidizing agency of persalts of iron rubiafine is changed first into rubiacine and then into rubiacic acid, and that the latter is reconverted by the action of reducing agents, such as sulphuretted hydrogen, first into rubiacine and then into rubiafine. The presence of rubiacine, however, in the liquor which has been used for dyeing with madder, seems to prove that its direct formation from rubian is possible.

Rubiagine.—This substance belongs to the same group of bodies which includes rubianine, rubiadine and rubiafine, and bears a strong resemblance to these substances in properties and composition. It scarcely ever appears in well-defined crystals. When its alcoholic solution is evaporated spontaneously, it is obtained in the shape of small lemon-yellow spherical grains, which, when crushed and examined under a lens, are found to consist of small crystalline needles grouped round a centre. Occasionally it has an orange tinge, but this is probably due to some impurity. When heated on platinum foil, it melts to a brownish-red liquid and then burns with flame, leaving a large quantity of carbonaceous residue which burns away with difficulty. When heated in a tube, it gives a small quantity of crystalline sublimate mixed with oily drops. When slowly heated between two watch-glasses, it melts to a brownish-red mass, but gives no sublimate. It is quite insoluble in boiling water, to which it hardly communicates a tinge of colour. It is more easily soluble in boiling alcohol than rubianine or even rubiadine, and does not crystallize out on the solution cooling, but is left, on evaporation of the alcohol, in crystalline masses as just described. It is soluble in concentrated sulphuric acid with a dark reddish-brown colour; the solution, on being heated, disengages sulphurous acid and becomes black. Boiling nitric acid dissolves it with a disengagement of nitrous acid to a yellow liquid, while some oily drops rise to the surface. On the solution cooling, a quantity of light yellow crystals, possessed of much lustre, are deposited. Whether these crystals are a product of decomposition, or whether they are the substance itself in a state of purity, the impurities having been destroyed by the nitric acid, I am unable to state. The latter is the more probable view. Rubiagine is soluble in boiling acetic acid with a yellow colour, and crystallizes out again, on the solution cooling, in small needles. Ammonia turns it red, and on boiling dissolves it with some difficulty, forming a blood-red solution, which on evaporation loses its ammonia and leaves the substance behind in the shape of small yellow crystals. It dissolves more easily in caustic soda, with the same colour. It is precipitated from its alkaline solution by acids in lemon-yellow flocks. The ammoniacal solution gives very slight precipitates with the chlorides of barium and calcium, the solution remaining red with chloride of barium, and becoming crimson with chloride of calcium. It is soluble in baryta and lime-water with a blood-red colour, and is reprecipitated by a current of carbonic acid. The alcoholic solution gives, on the addition of acetate of lead, at first no precipitate, but the colour of the solution becomes dark yellow, and after some time, provided the solution be not too dilute, an orange-coloured granular

precipitate falls, which is the lead compound of rubiagine. If no deposit is formed, then the addition of water causes an orange-coloured flocculent precipitate, which, after being separated by filtration and washed with water in order to remove the acetate of lead, is found to be very little soluble in boiling alcohol, but is easily soluble in a boiling alcoholic solution of acetate of lead with a dark yellow or orange colour. Acetate of copper changes the colour of the alcoholic solution from light yellow to brownish-yellow, and after some time an orange-coloured precipitate is formed. When rubiagine is treated with a boiling solution of perchloride of iron, the solution acquires a darker colour, but does not assume the deep brownish-purple characteristic of solutions of rubiafine and rubiacine in that menstruum. The liquid being filtered boiling hot, deposits on cooling a quantity of yellow shining scales, but the addition of muriatic acid produces no further precipitate. These scales dissolve easily in boiling alcohol, and the solution on cooling and standing deposits a number of small yellow grains and nodules consisting of crystalline needles, which are apparently nothing but rubiagine itself, for they are not capable of sublimation, and their alcoholic solution is not precipitated by acetate of lead. The greatest part of the rubiagine is left undissolved by the perchloride of iron in the shape of a yellowish-brown powder, which does not dissolve on treating it with an additional quantity of the iron salt. Boiling muriatic acid changes the colour of this powder to yellow, and it has then all the properties of rubiagine. Rubiagine is therefore not changed into rubiacic acid by the action of persalts of iron. Notwithstanding the great resemblance which rubiagine bears to the other bodies belonging to the same series, its reactions prove it to be a distinct substance. It is distinguished from rubianine by its insolubility in water; from rubiadine, for which it might most easily be mistaken, by its being incapable of sublimation; and from rubiafine by its not being convertible into rubiacic acid. Its behaviour towards acetate of lead, which is different from that of all the other three substances, also serves to characterize it.

The analysis of rubiagine gave the following results:—

0·3800 grm., prepared directly from madder, gave 0·9490 carbonic acid and 0·1760 water.

In 100 parts it contained therefore—

Carbon	68·10
Hydrogen	5·14
Oxygen	26·76

There are two formulæ with which this analysis corresponds, and both of which explain the formation of the substance equally well, viz. $C_{28}H_{14}O_{10}$ and $C_{44}H_{17}O_{13}$. These formulæ require respectively in 100 parts—

	$C_{28}H_{14}O_{10}$.	$C_{44}H_{17}O_{13}$.
Carbon	67·13	68·57
Hydrogen	4·89	4·41
Oxygen	27·98	27·02

I am unwilling to draw any inference from the greater or less correspondence of either of these calculations with the experimental result, because I am not convinced of the absolute purity of the specimen employed for analysis.

The lead compound of rubiagine was prepared by adding a small quantity of an alcoholic solution of sugar of lead to a concentrated alcoholic solution of the substance, taking care not to employ an excess of the precipitant. The orange-coloured precipitate was collected on a filter, washed with alcohol, dried and submitted to analysis.

0·4610 grm., dried in the water-bath, gave 0·5290 carbonic acid and 0·1110 water.

0·2010 grm. gave 0·1460 sulphate of lead, containing 0·10742 oxide of lead.

In 100 parts it contained therefore—

Carbon	31·29
Hydrogen	2·67
Oxygen	12·60
Oxide of lead	53·44

These numbers do not decide between the two formulæ, since they correspond equally well with $C_{22}H_{14}O_{10}+3PbO$ and $C_{44}H_{17}O_{13}+4PbO$, as the following calculation shows:—

	Eqs.			Eqs.		
Carbon . . .	32	192	30·91	44	264	31·73
Hydrogen . .	14	14	2·25	17	17	2·04
Oxygen . . .	10	80	12·89	13	104	12·53
Oxide of lead .	3	335·1	53·95	4	446·8	53·70
		621·1	100·00		831·8	100·00

If $C_{22}H_{14}O_{10}$ be the true formula of rubiagine, then it is formed by rubian taking up 4 equivs. of water and splitting up into 1 equiv. of rubiagine and 2 equivs. of sugar, as seen by the following equation:—

2 equivs. of Sugar . . . $=C_{24}H_{24}O_{24}$
1 equiv. of Rubiagine . . . $=C_{22}H_{14}O_{10}$
$C_{56}H_{38}O_{34}$ $=$ $C_{56}H_{34}O_{30}$ = 1 equiv. of Rubian. + H_4O_4 = 4 equivs. of Water. $C_{56}H_{38}O_{34}$

If, on the other hand, $C_{44}H_{17}O_{13}$ be the correct formula, then 1 equiv. of rubian loses 5 equivs. of water, and splits up into 1 equiv. of rubiagine and 1 equiv. of sugar, for

$$C_{44}H_{17}O_{13}+C_{12}H_{12}O_{12}+5HO=C_{56}H_{34}O_{30}.$$

Rubiadipine.—This substance is a characteristic product of the fermentation of rubian. I have never subjected rubian to the action of ferment, under ordinary circumstances, without being able to detect it among the bodies formed. In its appearance and general properties it resembles rubiretine. It differs from the latter in always remaining soft and viscid, and never becoming hard and brittle, however long it may be heated. It is similar in appearance to a semifluid fat tinged with

colouring matter. Its colour is yellowish-brown. When heated on platinum foil it melts to a brown liquid and then burns with a bright flame, leaving a carbonaceous residue. When heated in a tube it evolves acrid fumes, similar to those produced by fat when exposed to destructive distillation. It is not much affected by boiling nitric acid, but concentrated sulphuric acid chars it when heated. When thrown into boiling water rubiadipine melts, forming oily drops, which rise to the surface. It is soluble in caustic alkalies with a blood-red colour, but the solutions do not froth when boiled like solutions of soap. The ammoniacal solution gives only a slight precipitate with chloride of barium. On adding to the alcoholic solution a small quantity of acetate of lead, a pale reddish-brown precipitate is formed, which is the lead compound. This precipitate is insoluble in boiling alcohol, but dissolves entirely when an excess of acetate of lead is added to the boiling liquid, forming a dark brownish-red solution. From this solution it is again precipitated by water, and after filtering and washing is found to be again insoluble in boiling alcohol. In its behaviour to sugar of lead it therefore resembles rubiagine. The alcoholic solution gives no precipitate on the addition of acetate of copper. The substance itself cannot be obtained in a state fit for analysis, I therefore confined myself to the examination of the lead compound formed in the manner just described. The quantity of the substance obtained was, nevertheless, so small that I had only sufficient for one analysis at my disposal.

0·2020 grm., dried at 100° C., gave 0·3770 carbonic acid and 0·1260 water.

0·1150 grm. gave 0·0490 sulphate of lead, containing 0·03605 oxide of lead.

These numbers lead to the formula $C_{30}H_{24}O_5 + PbO$, as the following calculation shows:—

	Eqs.		Calculated.	Found.
Carbon	30	180	50·60	50·89
Hydrogen . . .	24	24	6·74	6·93
Oxygen	5	40	11·26	10·83
Oxide of lead . .	1	111·7	31·40	31·35
		355·7	100·00	100·00

If this formula represents the true composition of rubiadipine, I confess I am unable to explain its formation from rubian. The great excess of hydrogen contained in it, shows that some substance must be formed simultaneously containing a large proportion of oxygen, but which has hitherto escaped detection.

The experiments above detailed prove that the decomposition which rubian undergoes by fermentation, does not differ in its general nature from that which results from the action of acids or alkalies. The decomposing effect of the ferment extends like that of these agents to three portions of rubian. The first portion of rubian loses water and gives rise to the formation of alizarine. The second loses water and produces rubiretine and verantine in equivalent proportions. The third takes up water and gives sugar and rubiafine, or it takes up 1 equiv. more of water, and yields sugar

and rubiagine. The rubianine produced by acids, and the rubiadine formed by alkalies, give place, when ferment is the decomposing agent, to rubiafine and rubiagine. The rubiadipine, in consequence of the uncertainty of its nature and origin, and the minute quantity in which it is formed, I leave out of consideration. The relative proportion in which the various products of decomposition are formed, seems to be about the same in the case of ferment as when acids or alkalies are employed. Alizarine is formed in the smallest quantity; of rubiretine and verantine a little more is produced, but the sugar and the rubiafine and rubiagine exceed all the others in amount.

It appears further from these experiments, that the ordinary process of dyeing with madder is, in fact, mainly a process of fermentation, that it consists essentially of a re-arrangement of the elements of rubian induced by the action of ferment, whereby a formation of colouring matter takes place, and that the precautions necessary to be taken in regard to the regulation of the temperature in madder dyeing have reference principally to the progress of the fermentation. The extraordinary rapidity with which this process of fermentation is completed, is the only circumstance which distinguishes it from other processes of a similar nature.

A very interesting question now arises, suggested by the analogy which must be presumed to exist between this and other processes of fermentation, viz. By what means is the action of the ferment on rubian either destroyed, retarded or promoted; and do not any means exist of so modifying the action as to lead to the formation of particular substances in preference to others? With the view of throwing some light on this question, I instituted a series of experiments, which I shall now proceed to describe.

Having taken a solution of rubian and mixed it with a quantity of ferment sufficiently large to effect its decomposition under ordinary circumstances, I raised the temperature of the mixture to the boiling point and kept it boiling for a short time. After the mixture had stood for some days exposed to a moderate temperature, I found that the rubian had not undergone the least change. The liquid remained yellow and bitter, and after filtration and evaporation left a residue of rubian with its usual appearance and properties.

I took in the next place a quantity of ferment, dried it slowly at a moderate temperature, reduced it to a fine powder and mixed it with a solution of rubian. After the mixture had stood for some days, the rubian was entirely decomposed. The filtered liquid left on evaporation a quantity of sugar, and the residual mass on the filter, which was interspersed with numerous small yellow crystals, was treated with boiling alcohol, which, after being filtered boiling hot and allowed to cool, deposited a large quantity of rubiafine in crystals. The alcoholic liquid, on being examined in the usual manner, was found to contain besides rubiafine, alizarine, rubiagine, rubiretine and verantine, the two latter being rather less in amount than usual.

After drying the ferment at a moderate temperature, then heating it for some hours

in a water-bath, before adding it to a solution of rubian, no apparent change took place for some time, but gradually the rubian began to disappear, and after two months was entirely decomposed. The filtered liquid left on evaporation a quantity of sugar, and the residue on the filter, on being treated with alcohol, yielded a solution which contained rubiafine, and a pretty large quantity of rubiretine and verantine, but no alizarine.

To a solution of rubian I now added a sufficient quantity of ferment to effect its decomposition when used alone, and then a small quantity of sulphuric acid. The mixture remained apparently unchanged for some time. The liquid was filtered, the acid was neutralized with carbonate of lead, the liquid was then again filtered, and left on evaporation a yellowish-red, bitter, glutinous substance, which was apparently a mixture of rubian and sugar. The mass left on the filter was treated with boiling alcohol, which was then found to contain a trace of alizarine, a little rubiagine, and a large quantity of rubiretine and verantine.

The same experiment was performed, substituting for the sulphuric acid a minute quantity of carbonate of soda. This had the effect of completely dissolving the ferment, forming a solution to which the rubian imparted a red colour. After standing for some time, the rubian was entirely decomposed, for on neutralizing the soda with sulphuric acid, a yellow precipitate fell, while the liquid became colourless. The latter being filtered, the acid was neutralized with carbonate of lead, and the liquid being again filtered left on evaporation a quantity of sugar mixed with sulphate of soda. The mixture of ferment with the products of decomposition yielded to boiling alcohol a large amount of rubiafine, rather more than the average quantity of alizarine, and a moderate quantity of rubiretine and verantine, but no rubiagine. I repeated this experiment, using caustic soda instead of carbonate of soda; but having employed rather too large a quantity of alkali, I found that the action of the ferment was very much retarded, so much so that after standing for some days there was still a quantity of undecomposed rubian present; and among the products of decomposition formed there was little or no alizarine, rubiafine or rubiagine, but a large quantity of rubiretine and verantine. The addition of lime water produced a similar effect to that of carbonate of soda, though of not quite so marked a character.

Having mixed a solution of rubian with ferment in the usual manner, I added a small quantity of sugar of lead. The ferment, which had been previously diffused through the liquid, was immediately precipitated by the lead salt in brown flocks, leaving a clear yellow solution floating above it. After standing however for some days the colour of the solution became gradually paler, and at length almost disappeared. After filtration and evaporation it left a small quantity of sugar. The mass left on the filter was purple, and contained oxide of lead. It was treated with cold sulphuric acid, which turned it red. The acid liquid after filtration was neutralized with carbonate of lead, and again filtered, when it appeared colourless, and produced no precipitate with basic acetate of lead, a proof that it contained no rubian. The mass

which had been treated with cold sulphuric acid, was then treated with boiling alcohol, which on being filtered and allowed to cool deposited some crystallized rubiafine, and was found to contain a trace of alizarine and a large quantity of rubiretine and verantine. It appears therefore that even sugar of lead, which produces an insoluble compound with the ferment, is incapable of arresting the action of the latter on rubian.

The same experiment was made, using corrosive sublimate instead of sugar of lead. The action of the ferment was in this case considerably retarded, for the yellow colour of the liquid did not entirely disappear, even after several days. The filtered liquid left on evaporation some corrosive sublimate with a little rubian, but no sugar. The mass on the filter was treated with boiling alcohol, which was then found to contain no alizarine, rubiafine or rubiagine, but a considerable quantity of rubiretine and verantine.

Arsenious acid had a very similar effect to sugar of lead and corrosive sublimate, that is to say, it retarded the action of the ferment, prevented the formation of alizarine, and promoted that of rubiretine and verantine.

The addition of a large quantity of alcohol to a mixture of rubian and ferment had likewise the effect of retarding, though not of altogether preventing the fermentation. A great part of the rubian remained undecomposed, while the remainder had given rise to the formation of a small quantity of alizarine and a large quantity of rubiretine and verantine.

A solution of rubian having been mixed with ferment, I poured the mixture into a bottle, and then added a quantity of oil of turpentine, after which the whole was well shaken up and left to stand. The decomposition of the rubian was much retarded, and took several days for its completion. The oil of turpentine floating on the surface was removed. The liquid underneath was colourless. After filtration and evaporation it left a quantity of sugar. The remaining products of decomposition were rubiafine, a trace of alizarine, and a large quantity of rubiretine and verantine, but no rubiagine.

From these experiments, which seem to me sufficiently decisive to require no further confirmation, I draw the following inferences:—

1. There exist no means, short of the complete destruction of the ferment, capable of arresting its action on rubian, except exposing it while in a moist state to the temperature of boiling water. Even when exposed to that temperature, after having been previously dried, its fermenting power is not entirely lost, but merely weakened.

2. By the addition of various substances, usually classed as antiseptic, such as sulphuric acid, arsenious acid, sugar of lead, corrosive sublimate, alcohol and oil of turpentine, during the process of fermentation the action of the ferment is not destroyed; it is merely retarded and modified.

3. The more the action of the ferment on rubian is retarded, the more rubiretine and verantine, and the less alizarine are formed, so much so that in some cases the

alizarine disappears entirely from among the products of decomposition, which then consist almost solely of rubiretine and verantine. The formation of rubiafine and rubiagine is promoted when the action of the ferment is moderately retarded, but diminishes again, or entirely ceases when the retardation is very great. Of the two, the rubiagine is the first to disappear when any retardation takes place.

4. By the addition of small quantities of alkalies during the process of fermentation, the action is, as regards its duration, if not promoted, at all events not retarded; and as regards the relative quantities of the various substances produced, the amount of alizarine is thereby decidedly increased, while that of the rubiretine and verantine is diminished.

These experiments also confirm the view derived from analytical results, that there is a mutual relation and interdependence on the one hand between rubiretine and verantine, and on the other between rubiafine and rubiagine and the sugar, whereas alizarine occupies an independent position; for rubiretine is never found among the products of decomposition by fermentation without an accompaniment of verantine, though both may be present to the exclusion of all other products; and the formation of sugar always indicates that of rubiafine or rubiagine, whereas all these substances may be present without a trace of alizarine being at the same time produced.

The deleterious effect resulting from the presence of acids in the dye-bath during the process of madder dyeing hereby finds an additional explanation. Not only do acids act injuriously by seizing hold of the mordants with which the colouring matter ought to combine, not only do they allow the constituents of the root which are injurious in the process to have full scope by depriving them of the alkalies or alkaline earths with which they would otherwise unite, but they also retard the peculiar process by which the alizarine is formed, and even lead to the formation of deleterious substances at the expense of the colouring matter itself.

In order to place in a more striking light the influence exerted respectively by acids and alkalies during the process of the fermentation of rubian, I will here give the results of an experiment to ascertain quantitatively the amount of the various products of decomposition formed on the addition of either during the process. For this purpose I took 5·59 grms. rubian, dissolved it in water, added to the solution a quantity of ferment, and mixed both together very well. I then divided the mixture into two equal parts, and added to one half a small quantity of carbonate of soda, to the other a little sulphuric acid. Both were allowed to ferment for a length of time, and the portion insoluble in water was treated in both cases with boiling alcohol. The alcohol deposited on being filtered boiling hot a quantity of rubiafine, which was collected on a filter and weighed. To the alcobolic liquid I added acetate of alumina. The precipitate thereby occasioned was separated by filtration, washed with alcohol and decomposed with boiling muriatic acid. The red flocks thus obtained were collected on a filter, washed, dried and weighed. They consisted of alizarine, verantine and rubiafine. After being weighed, they were treated with boiling dilute nitric

acid, which destroyed the alizarine, leaving the two other substances behind in the shape of a yellow powder, which was filtered, washed, dried and weighed. By deducting its weight from the total weight of the three, the weight of the alizarine was ascertained. The liquid filtered from the alumina precipitate deposited on the addition of sulphuric acid and water a yellow powder, which was collected on a filter, washed, dried and weighed. It was then treated with a little cold alcohol. This left undissolved a quantity of rubiagine, which was again collected on a filter, dried and weighed. The alcohol left on evaporation a dark brown mass, the fatty nature of which showed that it contained rubiadipine in addition to rubiretine. Now I obtained from that half of the solution to which carbonate of soda had been added, the following quantities of these various substances:—0·323 grm. alizarine, 0·220 grm. rubiafine, 0·167 grm. of the mixture of rubiafine and verantine, 0·250 grm. rubiagine, and 0·170 grm. of the mixture of rubiretine and rubiadipine. From the other half, to which sulphuric acid had been added, I obtained the following quantities of the same bodies:—0·2030 grm. alizarine, 0·340 grm. rubiafine, 0·157 grm. of the mixture of rubiafine and verantine, 0·310 grm. rubiagine, and 0·230 grm. of the mixture of rubiretine and rubiadipine. In both cases a quantity of rubian remained undecomposed, but the quantity actually decomposed was capable of being approximately determined from the quantities of products of decomposition formed. Assuming the formula of rubiafine to be $C_{28}H_{18}O_9$, that of rubiagine $C_{28}H_{14}O_{10}$, assuming further that the mixture of rubiafine and verantine consisted entirely of the latter substance, by which no great error is committed (since the quantities of rubiafine and verantine which one atom of rubian is capable of yielding are to one another as 277 to 258), and leaving out of consideration the trifling quantity of rubiadipine formed (the rubiretine being given by the amount of verantine), then the quantities of the various substances obtained correspond respectively to the following quantities of rubian:—

		Rubian.		Rubian.
Alizarine	.	0·323 corresponds to 0·407	0·203 corresponds to 0·255	
Rubiafine	.	0·220 corresponds to 0·484	0·340 corresponds to 0·748	
Rubiagine	.	0·250 corresponds to 0·533	0·310 corresponds to 0·661	
Verantine	.	0·167 corresponds to 0·394	0·157 corresponds to 0·371	
		1·818		2·135

Hence it appears that though the amount of rubian which actually underwent decomposition was less when carbonate of soda was added than when sulphuric acid was employed in addition to the ferment, still the amount of the alizarine produced was greater in the former than the latter case, while the amount of almost all the other substances was proportionally less. In using carbonate of soda, the quantity of alizarine formed amounted to 17·7 per cent., in using sulphuric acid it amounted to 9·5 per cent. of the rubian decomposed. The quantity which should be formed, if the rubian were entirely converted into alizarine, is 79·3 per cent.

In the first part of this paper I have pointed out the possibility which exists in theory of converting rubian entirely into alizarine, to the exclusion of every other product of decomposition; and though I cannot say that I have approached much nearer to its practical realization, still if, as the experiments just described prove, the fermentative process whereby alizarine is formed is of so plastic a nature as to be capable of yielding under different circumstances, sometimes more, sometimes less, occasionally none, of the latter substance, then the prospect of our being able so to modify it as to lead to the formation of a much larger quantity of alizarine from a given quantity of rubian than is at present possible, becomes less distant.

The experiments which I shall now describe were made in order to ascertain the effect produced on rubian by other fermentative substances besides that contained in madder itself.

I first took a solution of rubian and mixed it well with a solution of albumen made from white of egg. The mixture was allowed to stand in a moderately warm place for two months, but though the albumen had entered into a state of putrefaction, the rubian was still for the most part undecomposed, as was evident from the taste and colour of the liquid. At the bottom of the vessel there was found a small quantity of a dark reddish-brown deposit, which was collected on a filter. On treating this deposit with boiling alcohol, the latter acquired a red colour, and left on evaporation a small quantity of a yellow bitter substance, soluble in water, which only differed from rubian in being somewhat viscid. The remainder of the dark brown deposit I treated with a mixture of muriatic acid and alcohol, when it immediately became almost white, while the substance which had coloured it dissolved in the alcohol with a yellow colour. The alcohol was filtered from the insoluble part, which was probably merely modified albumen, and evaporated to dryness, when it left a reddish-yellow, uncrystalline residue. This residue was impure alizarine, for it gave on being heated in a tube a crystalline sublimate, it dissolved in caustic alkali with a violet colour, and its alcoholic solution became purple on the addition of acetate of copper. In the reddish-brown deposit it was doubtless contained in combination with some base, perhaps lime. The greatest part of the rubian remained in solution mixed with the albumen. The solution was slowly evaporated to dryness, when it left a red transparent substance like gum or varnish, which was treated with boiling alcohol. The alcohol acquired a reddish-yellow colour, and left on evaporation a yellowish-red, deliquescent, bitter residue, consisting apparently of rubian mixed with some nitrogenous substance. It was entirely soluble in water with a reddish colour. This solution gave with acetate of lead a copious brown precipitate, the supernatant liquid being almost colourless, but with acids and alkalies it gave the usual reactions of a solution of rubian. The greater part of the gum-like substance was of course insoluble in alcohol. On being treated with a mixture of sulphuric acid and alcohol in the cold, an additional quantity of yellow liquid was obtained, which after filtration, neutralization with carbonate of lead and evapora-

tion, left a reddish, deliquescent residue similar to the last. It appears, therefore, that the action of albumen on rubian is but slight.

In order to ascertain what effect caseine has on rubian, I mixed a solution of the latter with a quantity of milk, and allowed the mixture to stand in a warm place for several days, until the smell indicated that the caseine had entered into a state of putrefaction. The liquid, which was still yellow and bitter, was filtered from the caseine, which had separated in yellow flocculent masses, and basic acetate of lead was added, which produced a red precipitate. This precipitate, after filtering and washing, was decomposed with cold sulphuric acid; the excess of sulphuric acid was removed with carbonate of lead; and after passing sulphuretted hydrogen through the filtered liquid to precipitate a little lead contained in the solution, it was again filtered and evaporated, when it left a quantity of rubian possessing the usual properties of that substance, with the exception of its being somewhat viscid. The caseine on the filter after being washed with water was treated with boiling alcohol, which deprived it of its yellow colour, and rendered it white. The filtered liquid, which was yellow, gave no precipitate either with acetate of alumina or sugar of lead, proving the absence of alizarine and the usual products of decomposition of rubian. On evaporation it left a residue of rubian mixed with fat, the whole, with the exception of the fat, being soluble in water.

A similar negative result was obtained with gelatine and yeast. A solution of rubian being mixed with a solution of glue, the mixture after standing for several weeks began to emit a putrid smell, and acquired a reddish tinge, but remained bitter, and deposited nothing insoluble. On adding yeast to a solution of rubian, and allowing to stand until putrefaction commenced, no apparent change took place in the solution, which retained its yellow colour and bitter taste.

The action of emulsine on rubian was very different. The emulsine employed was prepared in the usual manner, by treating sweet almonds, after being pounded and pressed between paper to deprive them of their oil, with water, separating the milky liquid from the residue by straining, allowing it to stand until the fat had collected on the surface, and then precipitating the emulsine from the clear liquid underneath, by means of alcohol. Some emulsine prepared in this manner was placed in a solution of rubian, and well mixed up with it. The mixture was allowed to stand in a warm place for some days. By degrees the liquid became almost colourless, while the emulsine acquired a yellow colour. It was filtered and evaporated, when it left a quantity of emulsine. The yellow mass on the filter was treated with boiling alcohol, which became yellow, while the residue lost almost the whole of its colour. The alcoholic liquid was filtered and spontaneously evaporated, when it left a yellowish-red mass, among which crystals of alizarine were discernible. This mass was treated with cold water, in which a part dissolved with a yellow colour. The liquid after filtration and evaporation left a quantity of unchanged rubian. The part insoluble in water was dissolved again in alcohol, and to the solution was added

acetate of alumina, which produced a red precipitate. This precipitate, after filtration and washing with alcohol, was decomposed with muriatic acid, and the yellow flocks left by the acid were dissolved in alcohol, on the spontaneous evaporation of which there was left a mass of pure alizarine in well-defined yellow crystals. The liquid filtered from the alumina precipitate was evaporated to dryness, and the residue left was treated with water and muriatic acid, when a brown mass was obtained, which after filtering and washing was treated with cold alcohol. The alcohol left undissolved a brown powder, consisting probably of verantine, and after filtration and evaporation left a brown resinous substance, easily fusible when thrown into boiling water, and consisting doubtless of rubiretine. The quantity of alizarine formed seemed to be much larger in proportion to the rubian employed, and to the quantity of other substances formed, than in the case of the ferment of madder. Nevertheless, I must state, that on repeating the experiment I was unable to attain the same result, the alizarine being formed in much smaller proportion and giving place to other products of decomposition.

Lastly, I resolved to examine what effect, if any, would be produced on rubian by seme fermentative substance derived like that of madder from a vegetable root. For this purpose I chose the albuminous substance described by Braconnot as existing in the root of the *Helianthus tuberosus**. I selected this substance, because it has, like the ferment of madder, the property of causing a solution of sugar to undergo an acetous fermentation. It was prepared in the following manner. The tubers were cut into slices, then pounded in a mortar with a little water until the lumps had disappeared. The mass was then placed on a piece of calico, and the liquor expressed with the hands. The muddy liquid which ran through was then mixed with a considerable quantity of alcohol. This produced a gray precipitate, which was collected on a filter and well washed with cold alcohol. Some of this precipitate was then added to a solution of rubian, and the mixture was allowed to stand in a moderately warm place until it began to disengage a putrid smell. The liquid was then filtered, and evaporated to dryness. The residue was treated with boiling alcohol, which dissolved a part with a yellow colour, leaving undissolved a quantity of brown flocks, consisting probably of some of the ferment. The alcohol on evaporation left a residue, consisting of rubian with its usual appearance and properties, and apparently free from sugar. The substance left on the filter had acquired a brownish-yellow colour, which was not removable by washing with water. On being treated with boiling alcohol, it lost its yellow colour, which was now transferred to the alcohol. The alcohol after filtration and evaporation left a dark brown substance in the shape of a pellicle, which yielded nothing to boiling water. On being treated with cold alcohol, a brown powder resembling verantine was left undissolved, while the filtered liquid gave on evaporation a residue of a resinous nature, which melted when thrown into boiling water and became brittle again when cold, and consisted doubtless of rubire-

* Ann. de Chem. et de Phys. xxv. 358.

tine. The effect produced by this substance on rubian, therefore, though it does not equal in energy that of the madder ferment itself, or even of emulsine, exceeds that of albumen or caseine. As regards the substances produced by it, its action resembles that of madder ferment when retarded by the addition of antiseptic substances, and it confirms the law which I have deduced from previous experiments, viz. that the more slowly rubian is decomposed, the more rubiretine and verantine are produced.

It appears from these experiments, that none of the common and well-known fermentative substances, with the exception of emulsine, are capable of effecting in any considerable degree the decomposition of rubian, and that none of them, with that single exception, can be employed as a substitute for the ferment contained in madder itself, which produces an effect on rubian altogether *sui generis*. This circumstance alone, apart from all other considerations, would entitle the ferment of madder to be considered as an entirely distinct and peculiar substance, on which it will therefore be necessary to bestow a distinct name. For this purpose I venture to suggest the name of *Erythrozym* (from ἐρυθρὸς *red*, and ζύμη *ferment*) as most appropriately indicating its chief characteristic, and I shall now proceed to give a short account of its properties and composition.

When prepared in the manner above described by precipitation with alcohol, erythrozym is obtained as a chocolate-coloured granular mass. When dried it coheres into hard lumps, which are almost black, and are with difficulty reduced to powder. When the dry substance is heated on platinum foil it emits a smell somewhere between that of burning peat and burning horn, and then burns without much flame, leaving a considerable quantity of residue, which, on being further heated, is soon converted into a grayish-white ash, consisting almost entirely of carbonate of lime. If erythrozym be well mixed while in a moist state with water, a reddish-brown muddy liquid is formed, having all the appearance of a solution. It is, however, no solution; the erythrozym is merely suspended in the liquid, for on filtering through paper a clear liquid passes through, while a mucilaginous substance remains on the filter. The latter, on being mixed with a solution of rubian, exerts the usual decomposing effect on that substance, while the liquid, when tried in the same way, is found to be entirely without effect. Hence it follows that erythrozym, after having once been precipitated from its watery solution, even by alcohol, cannot again be dissolved in water. The liquid obtained by treating erythrozym with water and filtering, contains a small quantity of a substance, which, from its reactions, I conclude to be pectic acid, or some body nearly allied to it. In fact, the method of preparing erythrozym implies that all substances contained in the watery extract of madder, insoluble in alcohol, must be found mixed with it; but since the erythrozym itself by precipitation with alcohol becomes insoluble in water, these substances may afterwards be easily removed by treating with water. If the watery liquid in which the erythrozym is contained in a state of suspension be boiled, a sort of coagulation takes place, and the erythrozym separates in the shape of dirty red flocks, while the liquid retains a reddish colour. The same effect is produced by adding alcohol or salts, such as

common salt or sal-ammoniac, the substance separating in dark reddish-brown flocks, with a clear yellowish liquid floating above them. That erythrozym is not an uncombined substance, but a compound of an organic substance with lime, is proved by its behaviour towards acids. If it be treated with any acid, even acetic acid, its colour changes from reddish-brown to yellowish-brown, and the filtered liquid is found to contain a considerable quantity of lime. The yellowish-brown flocks left on the filter, after all the excess of acid has been removed, do not again form with water a mucilaginous liquid like the original substance; and even an addition of lime water, though it restores the original chocolate colour, does not reproduce that peculiar condition of suspensibility in water characteristic of it in its original state. The brown substance into which erythrozym is changed by the action of acids is soluble in caustic alkalies, forming pale purple turbid liquids. The ammoniacal solution gives reddish-brown flocculent precipitates with most earthy and metallic salts. When the solution in caustic soda is boiled, a disengagement of ammonia takes place. If erythrozym be treated with boiling nitric acid, it is dissolved and decomposed with a disengagement of nitrous acid. A small quantity of a white flocculent substance remains behind. Concentrated sulphuric acid chars it on heating.

If erythrozym be mixed with water, and the mixture be allowed to stand for a length of time in a warm place, signs of a more active process of fermentation begin to show themselves, especially in summer weather; bubbles of gas are given off, and a peculiar smell is emitted, which, though disagreeable, cannot exactly be called putrid. During this process, which is evidently one of putrefaction in the stricter sense, the erythrozym loses its sliminess, and is converted into a red flocculent mass, which may easily be separated by filtration from the liquid. The latter is clear, colourless and quite neutral. After erythrozym has passed through this second stage of decomposition, its power of decomposing rubian is found to have lost much of its intensity. It is during the first period of its decomposition, when no apparent change is taking place, that this power is most energetically exerted. During the second, or more strictly putrefactive stage, it acquires, however, the property of decomposing sugar. If erythrozym be mixed with a solution of cane sugar, and the mixture be allowed to stand for a considerable time until gas begins to be disengaged, the solution acquires by degrees a decided acid reaction. What the acid is which is thereby formed, I have not yet ascertained.

The erythrozym which I submitted to analysis, was prepared by precipitating it from an extract of madder with tepid water, by means of alcohol, collecting it on a filter, then treating it repeatedly with boiling alcohol until all matter soluble therein was removed, and then washing it on a filter with cold water until the percolating liquid no longer gave a precipitate with sugar of lead, after which it was rapidly dried in the water-bath. It follows from the analyses which I have made, that the amount of lime which it contains is tolerably constant, and that it must consequently be considered as a definite compound of an organic substance with lime.

I. 0·6220 grm., dried at 100° C. and burnt with oxide of copper and chlorate of potash, gave 0·8670 carbonic acid and 0·2365 water.

0·7770 grm. gave 0·4035 chloride of platinum and ammonium.

0·9630 grm. gave on being incinerated 0·2350 carbonate of lime.

II. 0·4885 grm. of another preparation gave 0·6865 carbonic acid and 0·2060 water.

0·1540 grm. gave on being incinerated 0·0370 carbonate of lime, containing 0·02076 lime = 13·48 per cent. After being treated with sulphuric acid and again heated, it weighed 0·0500 grm., which, estimated as sulphate of lime, is equivalent to 0·02062 lime = 13·39 per cent.

From these numbers may be deduced the formula $C_{56}H_{34}N_2O_{40}+4CaO$, as the following calculation shows:—

	Eqs.		Calculated.	I.	II.
Carbon	56	336	40·48	40·93	41·20
Hydrogen	34	34	4·09	4·22	4·68
Nitrogen	2	28	3·37	3·26	
Oxygen	40	320	38·57	37·90	
Lime	4	112	13·49	13·69	13·48
		830	100·00	100·00	

If this be the true composition of erythrozym, it stands in a very interesting relation to that of rubian. If to 1 equiv. of rubian be added the elements of 2 equivs. of nitric acid, the sum will represent the composition of the organic substance contained in the erythrozym in combination with lime, $C_{56}H_{34}O_{30}+2NO_5=C_{56}H_{34}N_2O_{40}$.

I shall now give the results of an analysis of erythrozym which had been employed for the decomposition of a quantity of rubian, and then treated successively with cold water and boiling alcohol until all the products of decomposition were entirely removed.

0·5330 grm., dried at 100° C. and burnt with oxide of copper and chlorate of potash, gave 0·8325 carbonic acid and 0·2220 water.

0·2780 grm. gave 0·1835 chloride of platinum and ammonium.

0·0645 grm. gave on being incinerated 0·0130 carbonate of lime, containing 0·00729 lime.

These numbers lead to the following composition:—

	Eqs.		Calculated.	Found.
Carbon	52	312	44·82	44·99
Hydrogen	32	32	4·59	4·62
Nitrogen	2	28	4·02	4·14
Oxygen	30	240	34·51	34·95
Lime	3	84	12·06	11·30
		696	100·00	100·00

If this composition be compared with that of the substance in its undecomposed state, the exact nature of the change which it undergoes during the process of fermentation will be apparent. It appears that the change consisted in this case in the loss of 4 atoms of carbonic acid, 2 atoms of water and 1 of lime, for

$$C_{52}H_{32}N_2O_{30}+3CaO+4CO_2+2HO+CaO=C_{56}H_{34}N_2O_{40}+4CaO.$$

It appears also that no loss had been sustained in the nitrogen. The atom of lime lost was probably abstracted by the carbonic acid disengaged at the same time.

In order to obtain, if possible, the organic substance, which is contained in the erythrozym in combination with lime, and to which the name of erythrozym ought perhaps to be restricted, in a free state, I prepared an extract of madder with tepid water, and added to it tartaric acid. A brown precipitate was produced, which was collected on a paper filter, washed with water in order to remove the excess of acid, then treated with boiling alcohol, until everything soluble in that menstruum was removed, and lastly, washed with cold water, in order to separate any pectic acid which might be present; after which it was dried. Its analysis showed, however, that the acid had removed only half of the lime, and that the substance itself must, during the process of purification, have undergone decomposition.

0·5695 grm., burnt with oxide of copper and chlorate of potash, gave 0·9585 carbonic acid and 0·2600 water.

0·5940 grm. gave on being incinerated 0·0900 carbonate of lime, containing 0·0505 lime = 8·50 per cent.

0·2835 grm. gave on being incinerated, and then treated with sulphuric acid, 0·0560 sulphate of lime, containing 0·02310 lime = 8·14 per cent. The average per-centage of lime was therefore 8·32.

The nitrogen was not determined; but presuming no loss to have taken place in that constituent, then these numbers correspond to the following composition:—

	Eqs.		Calculated.	Found.
Carbon	52	312	48·00	47·68
Hydrogen . . .	30	30	4·61	5·07
Nitrogen . . .	2	28	4·30	
Oxygen	28	224	34·48	
Lime	2	56	8·61	8·32
		650	100·00	

It appears, therefore, that the decomposition of the substance had advanced in this case still further even than in the last, as it contained 2 equivs. of water less.

The last specimen I examined was one which was prepared in the usual manner by precipitation with alcohol, then mixed with water and allowed to decompose until bubbles of gas began to be disengaged, and the smell peculiar to this substance when in a state of putrefaction began to be emitted, then treated with boiling alcohol until nothing more was dissolved, and dried.

0·4630 grm., obtained in this manner and burnt with oxide of copper and chlorate of potash, gave 0·7260 carbonic acid and 0·1760 water.

0·5270 grm. gave 0·2705 chloride of platinum and ammonium.

0·2990 grm. gave on being incinerated 0·0720 carbonate of lime, containing 0·04040 lime = 13·51 per cent. After treatment with sulphuric acid, this yielded 0·0980 sulphate of lime, containing 0·04042 lime = 13·52 per cent.

In 100 parts it therefore consisted of—

Carbon	45·65
Hydrogen	4·22
Nitrogen	3·22
Oxygen	33·40
Lime	13·51

The only formula with which this composition agrees, and which is at the same time in accordance with the preceding formulæ, is $C_{52}H_{36}N_4O_{28}+3CaO$, which requires in 100 parts—

Carbon	46·60
Hydrogen	4·25
Nitrogen	3·13
Oxygen	33·48
Lime	12·54

From this formula it may be inferred, that during the further progress of decomposition erythrozym loses ammonia in addition to carbonic acid and water, for

$$C_{52}H_{36}N_4O_{28}+4CO_2+4HO+\tfrac{1}{2}NH_3=C_{56}H_{34}N_2O_{40}.$$

I shall conclude this part of my paper with a few remarks on the *vexata quæstio* of the existence or non-existence of more than one colouring matter in the madder root. Robiquet, the discoverer of alizarine, attributed the tinctorial power of madder partly to that substance and partly to another, on which he bestowed the name of purpurine. Gaultier de Claubry and Persoz were of opinion that there are two colouring matters in madder. Runge has described three substances obtained by him from madder, all of which he considers as colouring matters playing a part in the process of madder dyeing. Schiel, Debus and Wolff and Strecker all assume the existence of two distinct colouring matters. Notwithstanding, however, the array of authority in favour of this view, I have never been able to convince myself that the entire tinctorial power of madder was not due to alizarine alone, and that consequently all substances derived from madder, if endowed with any such power, owe it to their containing alizarine; and after having isolated and examined the primitive substance, from which all the bodies in madder endowed with a red or yellow colour, or capable of producing these colours, are derived, and after having exposed this substance to

the influence of all the reagents with which madder itself under ordinary circumstances is brought into contact, I find myself entirely confirmed in my opinion. I should indeed think it unnecessary to add anything confirmatory of the conclusions which must suggest themselves at once from the perusal of the preceding pages, but as Messrs. Wolff and Strecker have made it one of the special objects of their investigation to prove the existence of more than one colouring matter in madder, I think it may not be out of place here to add a few remarks to show how, in my opinion, these chemists, as well as their predecessors, have been misled, and also to give an account of some experiments still further confirmatory of the opinion which I have always held.

The second colouring matter, which, according to the chemists just mentioned, exists in madder in addition to alizarine, and which has received at various times the names of purpurine, madder-purple, and oxylizaric acid, possesses, according to those observers, the property of being easily soluble with a red colour in boiling alum liquor. Wolff and Strecker assert that this substance is peculiarly a product of fermentation, and in order to prepare it, they mix madder with water and yeast, allow the mixture to stand in a warm place until the effervescence produced by fermentation has ceased, and the liquid has acquired a strong acid reaction and contains alcohol, after which they strain the liquid through a cloth, wash the mass on the cloth with water, and then treat it with boiling alum liquor. From the bright red solution a substance separates on cooling in red flocks, which, as well as the orange-coloured flocks produced by adding sulphuric acid to the liquid, consist, according to them, entirely of purpurine without any trace of alizarine. They purify it by crystallization from alcohol. Now I have shown above that the fermentation of madder, which is in fact synonymous with the fermentation of rubian, is due to the action of a peculiar substance, which I have called erythrozym, on rubian; that the action of this substance is very rapid; that it is not accompanied by any disengagement of gas; that it is terminated long before any effervescence or any acid reaction of the liquid begins to appear; that the products of the action do not differ essentially from those due to the action of acids and alkalies; that the formation of alizarine in about the same proportion as when acids or alkalies are employed is one of the results of the process, and that yeast exerts no decomposing power on rubian whatever. Hence it necessarily follows, that if the purpurine of Wolff and Strecker be not found as such among the products of the fermentation of rubian, it must consist of a mixture of two or more of those products.

Now I have mentioned in the first part of this paper, that though alizarine and verantine are both perfectly insoluble in boiling alum liquor when acted on separately, yet that when a mixture of both is employed, the mixture is found to be soluble in alum liquor with the colour characteristic of purpurine. Hence I concluded that purpurine is in fact a mixture of those two substances, a view with which all that is mentioned regarding purpurine completely coincides. I may mention

incidentally, that in making this experiment it is necessary to treat the verantine with a little dilute nitric acid, in order to destroy the alizarine which usually accompanies it, and then to remove the acid by washing with water before employing it, and that it generally succeeds best when a large excess of alizarine is used.

To this synthetical proof of the opinion here advocated, I will now add a few analytical ones. I will show, in the first place, that purpurine prepared in the manner mentioned by Wolff and Strecker is a substance of very variable composition, but that the variations in its composition may be easily explained by supposing it to consist of alizarine and verantine in different proportions; and secondly, that by treatment with nitric acid purpurine yields unchanged verantine and an acid, which is identical with that formed by the action of nitric acid on alizarine.

In the course of my investigation I obtained at the termination of the process for separating the products of the fermentation of rubian, an alcoholic liquid, from which the verantine had been deposited, but still containing a substance, which, from its solubility in alum liquor, would by most chemists be called purpurine. This substance was precipitated from the solution with water. Its colour was brownish-yellow. It was treated with boiling alum liquor, to which it communicated a bright red colour. The liquid was filtered boiling hot, and deposited on cooling a quantity of red flocks. The residue was treated with fresh quantities of alum liquor, until on cooling very few flocks separated. A great proportion of the substance employed remained undissolved. The flocks deposited from the alum liquor were collected on a filter, and washed with water in order to remove all the alum. After drying they formed a dark reddish-brown powder, which was almost entirely soluble in alcohol. The alcoholic solution left on evaporation a bright red mass, in which no trace of anything crystalline was discernible. Its analysis gave the following results:—

0·4820 grm. gave 1·1240 carbonic acid and 0·1800 water.

0·8060 grm. left on being incinerated 0·0310 alumina=3·84 per cent.

After making the proper correction for the alumina, the quantity of which, in relation to that of the other constituents, seems to be indefinite, these numbers correspond in 100 parts to—

Carbon	66·13
Hydrogen	4·31
Oxygen	29·56

This composition does not differ very widely from that given for oxylizaric acid by Debus.

Now the formula $C_{56}H_{30}O_{19}=C_{14}H_5O_4+3C_{14}H_5O_6$ requires in 100 parts—

Carbon	66·14
Hydrogen	3·93
Oxygen	29·93

A quantity of material similar to the last, obtained on a different occasion, was treated in the same way with boiling alum liquor, and the deposit formed on the liquor cooling was submitted to analysis. It had a much lighter colour than the preceding, and when dissolved in alcohol, the latter left on evaporation crystals, apparently of alizarine, mingled with red crystalline masses resembling impure alizarine.

0·4000 grm. gave 0·9870 carbonic acid and 0·1390 water.

0·3840 grm. left on being incinerated 0·0060 alumina = 1·56 per cent.

After making the necessary correction for the alumina, these numbers correspond in 100 parts to—

Carbon	68·36
Hydrogen	3·92
Oxygen	27·72

The formula $C_{56}H_{30}O_{17} = 3C_{14}H_5O_4 + C_{14}H_6O_5$ requires in 100 parts—

Carbon	68·29
Hydrogen	4·06
Oxygen	27·65

These two specimens therefore of a substance prepared in the same way, both of which would, according to the definition of Wolff and Strecker, pass for purpurine, possessed a composition, which in the one case corresponded to a mixture of 1 equiv. of alizarine and 3 equivs. of verantine, in the other case to a mixture of 3 equivs. of alizarine and 1 equiv. of verantine. A still more manifest proof of the fact of purpurine not being a substance of uniform composition, is derived from an examination of the liquid from which these specimens were deposited. To the bright red liquid from which the last was deposited, I added after filtration muriatic acid and boiled. A yellow precipitate was produced, which was collected on a filter and washed. A small quantity of it being dissolved in alcohol, the alcohol left on evaporation crystals of apparently pure alizarine. Its analysis also showed that it consisted of alizarine almost in a state of purity.

0·2390 grm. gave 0·6040 carbonic acid and 0·0980 water.

In 100 parts it contained therefore—

		Alizarine.
Carbon	68·92	69·42
Hydrogen	4·55	4·13
Oxygen	26·53	26·45

I now prepared some so-called purpurine from garancine. The garancine was treated with boiling alum liquor, and the liquor was strained boiling hot through calico. On cooling there was formed a copious deposit, which was redissolved in fresh alum liquor. The deposit formed this time, which was very trifling, was

separated, and the substance contained in the liquid was precipitated with muriatic acid. The precipitate was yellow. Its analysis proved it to be almost pure verantine.

0·3685 grm. gave 0·8760 carbonic acid and 0·1400 water.

In 100 parts it contained therefore—

		Verantine.
Carbon	64·83	65·11
Hydrogen . . .	4·22	3·87
Oxygen	30·95	31·02

It appears therefore that the substance called purpurine cannot even be called a compound of alizarine and verantine, for it consists sometimes of one alone, sometimes of the other, sometimes of a variable mixture of both.

I now treated some purpurine, made in the same manner as the last, with boiling dilute nitric acid. Nitrous acid was disengaged, the bulk of the substance diminished very much, and its colour became lighter. After the action was completed, I allowed the liquid to cool, added water, collected the yellow flocks on a filter, and washed them with water to remove all the acid. After drying their colour was brownish-yellow, similar to that of pure verantine.

0·3820 grm. gave 0·9070 carbonic acid and 0·1240 water.

In 100 parts—

Carbon	64·72
Hydrogen	3·60
Oxygen	31·68

Its composition therefore, with the exception of a slight deficiency in the amount of hydrogen, was that of verantine.

The acid liquid filtered from the substance was evaporated almost to dryness, when it yielded a quantity of yellow crystals. These were washed with cold water, and then redissolved in a little boiling water. The boiling solution was decolorized with animal charcoal, and after being filtered boiling hot deposited on cooling a quantity of colourless crystals, having the appearance, and as their analysis showed, the composition of Laurent's naphthalic acid.

0·5230 grm. gave 1·1020 carbonic acid and 0·1770 water.

In 100 parts—

		Napthalic acid.
Carbon	57·46	57·83
Hydrogen . . .	3·76	3·61
Oxygen	38·78	38·56

Wolff and Strecker mention, that purpurine yields this acid when subjected to the action of nitric acid, but the verantine which is found in an undecomposed state, after the action of the nitric acid has ceased, seems to have eluded their observation.

From these experiments I infer that purpurine, madder-purple, and the various similar bodies derived from madder, owe their property as colouring matters to an admixture of alizarine, and that they simply consist of the latter substance in a state of impurity.

IV. *Observations on the Structure and Development of Bone.* *By* JOHN TOMES, *F.R.S., Surgeon-Dentist to the Middlesex Hospital, and* CAMPBELL DE MORGAN, *Surgeon to the Middlesex Hospital.*

Received April 22,—Read June 10, 1852.

THE structure and development of bone is a subject which has occupied the attention of physiologists both of present and past times, and holds a prominent place in their writings. From the time of CLOPTON HAVERS, who was the first to point out the vascular canals in bone, and whose name they have since borne, to the year 1850, when M. KÖLLIKER's elaborate work on Structural Anatomy appeared, physiological writers have dwelt at considerable length on this branch of their subject. All have, however, concluded with the admission that more remained to be learned before this important structure could be regarded as fully understood*.

It is the purpose of the authors in this communication, to lay before the Royal Society the results of an extended series of observations on the structure and development of bone. Such of these results as are novel might, perhaps, be described without reference to those points which are already well known. It will, however, be seen, in the subsequent pages, that they are in themselves, and in their relations to osseous tissue and its development, as well as to structural anatomy generally, of such a nature, as would hardly admit of an intelligible description apart from some consideration of the whole subject. Hence it will be necessary to point out the relations between that which is already known, and that which it is the special purpose of this paper to communicate, and it is proposed to consider the details of the subject as they present themselves in the progress of investigation with but little reference to authorities, adding in the form of notes, those statements which require acknowledgement, either as agreeing with, or as being opposed to, the views advanced in this paper.

In treating of the structure of bone, it is convenient to commence by describing the appearances which a thin transverse section from the shaft of an adult long bone presents when placed in the field of a microscope having a magnifying power of from 200 to 300 linear. In addition to the large central space which corresponds to the medullary cavity of the bone, the section is seen to be perforated by numerous small apertures, each of which is surrounded by a series of laminæ of osseous tissue concentrically arranged. Lying amongst the laminæ are many small cavities, from which minute tubes radiate. These were called bone-corpuscles by PURKINJE, who

* Mikroskopische Anatomie, von Dr. A. KÖLLIKER. Leipzig, 1850.

first described them; but latterly, with a more correct appreciation of their nature, the name of lacunæ has been substituted at the suggestion of Dr. Todd and Mr. Bowman*, who have also described the Haversian canals, their surrounding laminæ, and their lacunæ, under the inclusive term of Haversian systems. The whole substance of the bone is made up of Haversian systems, connected by irregularly-shaped patches of short laminæ which occupy the spaces between the systems (Plate VI. fig. 1 *b*). These have received the name of interstitial laminæ from Kölliker. In addition to the Haversian and interstitial laminæ, we have in most instances others that surround, or partly surround the whole, and form the outer surface of the bone. These, from the position they occupy, are called the circumferential laminæ. A similar series more or less perfect is found to form the wall of the medullary cavity.

If the section be taken from near the end instead of from the middle of the shaft of a long bone, the Haversian canals will appear much larger, and in the place of one great central opening we shall see numerous lesser ones, corresponding to the cancellous part of the bone. From whatever bone, or part of a bone, the section be taken, the arrangement of laminæ and lacunæ is substantially the same; the differences between the compact and cancellous portions consisting in variations in the relative quantities of the bone tissue and the size and number of the canals, and not in any real difference in the structure.

The elongated bones of some of the vertebrata, when cut transversely through their centres, are seen to be composed, at that part, of a single Haversian system. The rib of a Boa may be cited as an example.

Having drawn attention to the several parts which are recognised as entering into the composition of bone, the authors will now proceed to describe the results of their investigations under the subjoined heads:—

1st. The Haversian canals and other spaces.
2nd. The laminæ.
3rd. The lacunæ and canaliculi.
4th. The Haversian systems.
5th. Ossified cartilage of joints.
6th. Ossified cells.
7th. Bone tissue.
8th. Development of bone.
9th. Growth of bone.

Haversian and other Canals of Bone.—The Haversian canals have been described by all recent writers on the subject of bone; their variable size and not unfrequent anastomoses have been pointed out; and the fact of the larger apertures in the spongy parts of bone being similar in the structure of their parietes to the smaller ones in the denser parts of the osseous tissue has not failed to be recognized. It may be remarked, that whether the canals are large or small, their section presents an

* The Physiological Anatomy and Physiology of Man, by Dr. Todd and Mr. Bowman, vol. i. p. 109.

oval or circular outline, and that the walls of such canals have a tolerably uniform surface. When examining sections of bone it is necessary to bear this fact in mind, for on a close inspection it will be seen that there are other spaces which possess a different character, although up to the present time, so far as the authors know, this difference has not been recognized.

These spaces are irregular in shape, and have an irregular, festooned and often jagged outline, similar to that found on the surface of bone which has been removed by exfoliation, similar also to the surface left upon the fang of a tooth after a part has been absorbed. Such spaces correspond in shape to the peripheral outline of one or more of the Haversian systems, and are in fact subservient to the development of those systems, and necessarily precede their formation (Plate VI. figs. 2 *a*, 3 *a*, 4 *a*). It is proposed to call these spaces which are produced by absorption, *Haversian spaces*, as this name is indicative of their ultimate connection with the Haversian systems. In the Haversian canals we have surrounding laminæ, but in the spaces the boundaries are formed by portions of several systems, each of which has been in part removed in the formation of the spaces, as shown in figures 2 and 3, and Plate V., which, on being compared with figure 1, will illustrate the difference between the spaces and canals; allowance must, however, be made for the difference of size, as in figure 1 the parts are less magnified than in the other illustrations. In newly-formed bone situated near ossifying cartilage, the Haversian spaces are exceedingly numerous and large, frequently affording room for the development of two or more systems (fig. 5, Plate VI. fig. 24, Plate VIII.), while in older bone they are far less numerous, and generally less in size. In no case, however, are they wholly absent. They are found even in the bones of old subjects, and in connection with them newly developed systems.

This is a very important fact, as it demonstrates that the old tissue is removed in masses, and a new one developed in its place. It has long been taught that the older particles of an internal tissue are removed by absorption and new ones substituted, and this throughout the life of the individual. But the authors believe that they have demonstrated it for the first time.

On examining with care a series of sections, the Haversian spaces will be found in various conditions. In one place the space will have attained a large size, while in another part of the same section its commencement will be seen extending from one side of an Haversian canal. In a third instance, its occupation will have commenced, and its festooned margin will be lined by the peripheral lamina of an Haversian system. Then, again, examples may be found where one side of a space is becoming the seat of a new system, while the opposite one is undergoing further enlargement. In no case is there any difficulty in distinguishing between an enlarging Haversian space and a developing Haversian system. The authors have preparations which show that these conditions of absorption and reproduction take place in old as well as in young or middle-aged subjects; but it would appear that the frequency dimi-

nishes with the increasing age of the individual. It may however be observed in the bones of those who have passed the sixtieth year. The more recently formed systems differ from those of older date in the somewhat larger size of their lacunæ and canaliculi, and in the greater abundance of the latter, as shown in fig. 6, Plate VI.

Laminæ of Bone.—Lamination is a tolerably constant character of mammalian bone, although the degree of its distinctness is subject to considerable variation. In the bones of young subjects it is less pronounced than in those of mature animals (fig. 4, Plate VI.); it is also much less observable in the cancellous than in the compact tissue. When lamination reaches its highest degree of development, each lamina is seen to be made up of two parts, an outer, which is highly granular, composed oftentimes of a single line of large granules or cells*, as shown in Plate VI. fig. 8; and an inner portion, which is singularly clear and transparent, and to all appearance without granulation or any recognizable structure.

Kölliker has described and figured a somewhat similar appearance from a specimen treated with turpentine, but he does not seem to regard it as very readily discoverable in ordinary preparations†; there is, however, no difficulty in exhibiting this arrangement of structure in well-made sections, either simply polished or (which is better) put up in hard Canada balsam.

Very favourable views of lamination may be seen in transverse sections from the shafts of long bones; some of the most striking illustrations in the possession of the authors were obtained from the tibia of a subject the whole of whose bones were slightly hypertrophied, and from the femur of a limb which had from infancy been atrophied and useless.

Strongly marked laminæ, with their transparent and granular portions, are however not always met with; yet in their absence the observer will seldom fail to find laminæ of more uniform granularity surrounding the Haversian canals in well-marked concentric rings.

On examining the Haversian systems, it will be seen that the peripheral lamina has its internal surface marked by an even line, while the external is subject to slight bulgings, which correspond with and accurately fit into the indentations that form the margin of a pre-existing Haversian space (Plate VI. fig. 1). Hence the outer lamina of a system will present on its external surface a certain number of alternating dilatations and contractions; a peculiarity possessed by none of the more internal of the series. We may, however, find the whole of the laminæ of a system presenting different degrees of thickness on the opposite sides of a canal, from the latter being a little eccentric in its position. But when the eccentricity is considerable, as in the case illustrated in Plate VI. fig. 7, the laminæ are not all continued round the canal‡. Hence,

* The nature of these bodies will be more fully considered under the head of development and growth of bone.

† Kölliker, *oper. cit.* page 284. In 'The Microscopic Anatomy of the Human Body,' by A. H. Hassall, this appearance is indistinctly figured, but no description of it can be found in the letterpress.

‡ Kölliker, *oper. cit.* at page 283, states that in the eccentric systems the whole of the laminæ generally

in such a system, there are more laminæ on one side than on the other, and those on the side occupied by the greatest number are thicker in their centres than at their extremities, where they become gradually thinner, and are ultimately lost. The inner lamina, whether the systems are eccentric or not, forms, when the development is completed, a perfect ring, and not unfrequently presents a second peculiarity. The tissue of which it is composed is transparent, and affords, with our present means of investigation, little evidence of structure (Plate VI. figs. 6 and 7). It is transparent and glass-like, resembling that tissue which lines the Haversian canals in the antlers of the Cervidæ before they are cast (Plate VII. fig. 9).

The interstitial laminæ are abundant, and strongly marked in transverse sections of long bones, or in any sections of bone in which the Haversian systems are cut transversely. The laminæ vary both as to their number and length, and are usually more or less curved. They are arranged throughout the bone in well-defined isolated groups, in each of which the constituent laminæ are parallel (Plate VI. fig. 1 *b*). Professor Kölliker*, when treating of this subject, observes that it is difficult to account for the presence of the interstitial laminæ, and suggests that the appearance may perhaps be produced by the Haversian systems being cut obliquely, but at the same time admits that this explanation is not satisfactory. M. Kölliker had not recognized the presence of the Haversian spaces and the manner of their production and subsequent occupation, otherwise he would have seen that the interstitial laminæ are the remaining parts of Haversian systems, the larger portions of which had been removed by absorption. But that the term *interstitial laminæ* is already in use and has a definite meaning, the authors would have proposed the substitution of *partial Haversian systems*, as being more descriptive of these parts.

In addition to the laminæ of the perfect and imperfect Haversian systems, others that surround several linearly arranged systems are not uncommon, producing the appearance illustrated in Plate VI. fig. 5. In these instances a large oval system of laminæ has become occupied by several lesser ones. The occurrence of one system within another is by no means rare. We may then see the characteristic emarginated outline of the older system, and within this a second similar outline marking the periphery of the younger system, as shown in Plate VI. fig. 6, in which the lamination of each is delineated†.

The circumferential laminæ are the most external, and where they exist form the surface of the bone. Their occurrence, however, is by no means so constant as is generally described, and even when present they seldom extend perfectly round the bone. The authors have scarcely seen an example in which the laminæ have been continued without interruption around the shaft of a long bone, and in flat bones

encircle the canal, but that they are individually thicker on the one than on the other side. Although this may be the case in some instances it has been but rarely seen by the authors.

* Kölliker, page 289, *oper. cit.*

† This appearance is figured by M. Kölliker, but no reference is made to the peculiarity in the letterpress.

they are even less constant. When present they appear to indicate that the bone is nearly stationary in its growth as regards thickness, for in the fast-growing bones of young animals these laminæ are entirely absent, while in the bones of adults they are usually well-developed in some parts. In number they seem subject to considerable variation, and not unfrequently are arranged in different concentric series with three or four laminæ in each division, separated from the adjacent series by a broad and transparent lamina, suggesting the idea of periods of greater activity of growth, alternating with others of less activity. Like those of the Haversian systems, the circumferential laminæ are perforated by Haversian spaces and systems (Plate VII. fig. 10), and in many examples to such an extent that they are recognized only as interstitial laminæ; but their uniform direction parallel with the surface of the bone will satisfactorily indicate their previous existence as continuous circumferential laminæ. In this part of a bone we may sometimes discover a peculiarity of character, in the presence of Haversian systems, consisting of two or three laminæ, or of even a single lamina only, so small has been the preceding Haversian space.

In the progress of development canals are sometimes formed which proceed from the surface of the bone into its substance, and around these the circumferential laminæ are inflected, thereby forming systems, the laminæ of which are continuous with those of the surface of the bone. On the other hand, Haversian spaces not unfrequently occur which are continued from the surface towards the centre of the bone, cutting the circumferential laminæ abruptly across; systems are subsequently developed in these spaces; but in such instances the laminæ of the systems are not continuous with those of the surface (the latter appearance is shown in Plate VII. fig. 10).

In young rapidly growing bone the circumferential laminæ are replaced by a series, which, from the character of their course, might be termed the undulating laminæ. The bone in its growth sends off outrunning processes between those vessels of the periosteum which lie nearest the surface of the bone. These processes are formed of reduplicated laminæ which are continued from process to process, following the undulating surface of the bone for a considerable distance before they are lost. The growing processes as they increase in size and length arch over towards each other by the dilatation or bifurcation of the outer extremities. The salient points so formed come into contact and unite, thereby enclosing the vessels. The spaces enclosed in the manner described become the seat of Haversian systems. Hence we have at this period of growth, bone composed of Haversian systems with intervening undulating laminæ, a character by which the observer cannot fail to recognise young growing bone as differing from that of adult animals. Over the points where the processes have met and united, laminæ are extended which are continued outwards to form similar and more external processes; these in their turn become united and inclose spaces. This mode of increase by the development of outgrowing processes is repeated again and again until the rate of growth becomes

arrested, when the formation of ordinary circumferential laminæ is assumed in some cases to be again replaced by the development of undulating laminæ. It must however be remembered that in the rapidly growing bone of young subjects lamination is much less strongly pronounced than in the bones of the adult (Plate VI. fig. 4), and that in many cases it is indicated more distinctly by the arrangement of the lacunæ than by the presence of well-marked outlines in the laminæ themselves.

In addition to laminated tissue we sometimes find portions of superficial bone run in, as it were, between two or three Haversian systems, and without any appearance of lamination, but with a general transparency, and with lacunæ scattered through it of indefinite form, and wanting in that arrangement which prevails in laminated bone*.

Lacunæ of Bone.—In a transverse section of the Haversian systems the lacunæ are seen as elongated oval spaces, lying amongst, and with their long axes in the direction of, the laminæ; numerous canaliculi proceed from them, the bulk of which in this view pass off towards either the Haversian canals or the outer surface of the systems. The lacunæ are however somewhat different in appearance at different ages of the systems and of the subject. In youth they are large, numerous, and richly supplied with canaliculi; on the other hand, in an old subject they are less numerous and have fewer canaliculi. Moreover, they vary a little in character in different parts of the same preparation, according to the age of the particular spot in which they are examined (Plate VI. fig. 6). Then, again, they frequently exist without canaliculi; while in other cases they may be found, together with the canaliculi, in great part filled up with solid matter, leaving only a small round open space in their centre. This state of consolidation has not, so far as the authors are aware, been previously observed. It is however present to a considerable extent in the long bones of adults who have in infancy suffered from rickets, and whose bones have remained permanently distorted (Plate VII. fig. 12 *a* and *b*). More rarely a similar condition may be seen in the bones of those who have passed the middle period of life without having suffered from rickets in childhood. Hence consolidation must be regarded as a normal condition of the lacunæ, of occasional occurrence, rather than as the result of disease.

In favourable sections it may be shown that both the lacunæ and canaliculi have parietes, which are manifested by appearances similar to those observed in the dentinal tubes†. In lacunæ which have no canaliculi the walls are well-marked, and in

* Kölliker, *oper. cit.* p. 288, objects to the opinion of Arnold that the interstitial laminæ have a different origin from the external and internal circumferential laminæ, the former of which he believes to originate in the cartilage, the latter in the external and internal periosteum.

Kölliker's views are inserted in the text, but it is seen above that the observations of the authors do not coincide with those of either Arnold or Kölliker.

† This point will receive additional confirmation in a subsequent part of the paper, when the development of the lacunæ and canaliculi is described.

a transverse section of the latter the parietes are readily recognized, as shown in figure 11, Plate VII.

In a longitudinal section of Haversian systems we have the laminæ on either side of the canals cut at right angles, or nearly so, while immediately over the canals they are exposed in their breadth; in the one instance we look upon the cut edges, in the other upon the surface of the laminæ. The lacunæ in the two parts present differences in outline. In the former part they resemble those seen in the Haversian systems divided transversely, in the latter they approach a circular, or slightly oval figure, and send out canaliculi indifferently from all parts of their circumference. After examining the lacunæ from these three different points of view, it will be manifest to the observer that the normal form is that of a greatly compressed hollow sphere or oval, from which numerous minute tubes are continued. To this prevailing form we find numerous exceptions, which, although of not unfrequent occurrence, form but a small part of the whole number that may be seen in an ordinary preparation. The outlines assumed by the exceptional lacunæ are too varied and too irregular to admit of such a description as would embrace every departure from the ordinary form. It is however worthy of mention, that lacunæ may sometimes be met with, normal in form, but of three times the usual dimensions.

What has been said of the lacunæ of the Haversian systems will of course apply also to those occupying parts of systems known under the name of interstitial laminæ. In the circumferential laminæ the lacunæ are for the most part similar to those already described. But we have in this situation what may perhaps be regarded as modified lacunæ, presenting themselves in the form of elongated tubes arranged in bundles, or occurring singly, and passing more or less obliquely from the surface towards the interior of the bone (Plate VII. fig. 13). When these tubes attain a considerable length they are commonly bent at a sharp angle once or twice in their course, and at each flexure change their direction, presenting sometimes a loose resemblance to the letter z. When these tubules are divided transversely they exhibit parietes. On tracing them in parts abounding with lacunæ, it will be seen that they form lateral connections with the canaliculi, at the same time that they cross these as well as the lacunæ and laminæ obliquely. The presence of the oblique tubes is not however constant. In one part of the circumferential laminæ they will be abundant, while in another they will be sparingly present or altogether absent. Then, again, they may be seen in one series of laminæ, while in the contiguous set they are absent, but may reappear in a third and more deeply-seated series. They are, however, we believe, strictly confined to the limits of the circumferential laminæ, and are seldom present unless these are tolerably abundant.

The lacunæ situated in the transparent non-laminated bone, which is sometimes found on or near the surface, and to which we have before alluded, are less compressed in form than those hitherto described. They are subject to great irregularities of outline, and send off canaliculi equally from all parts of their circumference, thereby

imparting a peculiarity to the tissue which cannot fail to be remarked. The presence of persistent nuclei in the lacunæ has been questioned by recent authors; some state that they may be detected at times, while others regard their presence as very problematical. Mr. Goodsir* describes the lacunæ as containing a little mass of nucleated cells.

M. Kölliker†, after citing Schwann, Krause, Kohlrausch, Heischmann, Günther and Donders, all of whom believe in the persistence of the nuclei in the lacunæ, goes on to say that he has paid great attention to the subject. In the bones of an individual eighteen years old he found them after the sections had been treated with acid. The authors have had no difficulty in finding the nuclei in recent bone without the aid of chemical treatment. If a small fragment be taken from the spongy portion of a fresh bone and freed from adherent fat, the nuclei may be seen as small rounded bodies attached to the walls of the lacunæ; their appearance is shown in Plate IX. figs. 27 and 29. In dry sections of bone the nuclei are less readily recognized, although we may find them here and there. The authors have sections of a fossil bone from the Wealden (supposed to be Pterodactyle) in which all the lacunæ have well-defined nuclei (Plate VII. fig. 14).

Haversian Systems.—Having described the several parts entering into the formation of Haversian systems, it now remains to say a few words on the relations of these to each other, and to the other parts of bone which are not included under that term. The union of the Haversian and other systems of laminæ is seen, in a transverse section of a long bone, to be effected by the interposition of a layer of transparent tissue. In a recently-formed system the canaliculi do not appear to pass through this layer, but in older ones they are seen to pass across from the external lacunæ and to anastomose with those from the interstitial or circumferential laminæ, or with those of adjoining Haversian systems (Plate VII. fig. 10). After these intercommunications have been fully established, the connecting layer loses something of its original transparency, but not the whole, for in the bones of aged subjects it may still be distinguished.

In Dr. Todd and Mr. Bowman's 'Physiological Anatomy,' it is stated, on the authority of Mr. Tomes, that the canaliculi of adjoining systems anastomose but scantily. A more extended examination into the subject has shown this to be true of the more recently developed systems, but not of those of greater age. In addition to the connection of systems of laminæ by the juxtaposition of their external members, instances not unfrequently occur where several Haversian systems, linearly arranged, are encircled by a series of laminæ common to the whole. This is shown in Plate VI. fig. 5. But although we may find groups of systems thus bound together by enclosing laminæ, in addition to the general or partial investment by circumferential laminæ, such binding together is clearly not necessary to ensure the strength of the bone, as we see many

* Anatomical and Pathological Observations, by John Goodsir and Henry D. S. Goodsir, 1845.

† Kölliker, *oper. cit.* p. 296.

bones altogether destitute of circumferential laminæ, and very few with these laminæ complete; while the encircling of several Haversian systems with laminæ common to the whole is the exception rather than the rule.

In the progress of their investigations the authors have failed to discover any instances in which pre-existing laminæ, partially absorbed, have become continuous with newly-developed ones, end to end; indeed there seems good reason for supposing that such seldom, if ever occurs, otherwise the Haversian systems would not be so strongly marked, neither should we have the festooned outline to the systems lying against the cut ends of the laminæ, in the manner shown in Plates VI. and VII. figs. 1 and 10.

In examining Haversian systems divided transversely, one will be occasionally found in which the canal has been completely obliterated by the development of a lacunal cell in its centre. This condition is illustrated in fig. 1 *c*.

Ossified Cartilage of Joints.—Dr. SHARPEY has shown that beneath the articular cartilage lies a layer of bone produced by the gradual ossification of this tissue*. Professor KÖLLIKER† has observed this form of bone to be present in all the articulations, excepting that of the jaw and the hyoid bone, in which situations he has failed to detect it. The authors have numerous sections from the articular process of the lower jaw, in all of which it is present, and although in smaller amount than is usually found in corresponding parts of other bones, still it is sufficiently distinct. The peculiarity of the articular bone consists in the maintenance of the same arrangement of parts as existed in the cartilage prior to its conversion into bone. The cells for the most part are arranged in groups or in lines parallel with the long axis of the bone, each cell presenting a roundish mass surrounded by granules, and rendered rather indefinite in outline. Not uncommonly several cells become connected end to end, thus producing an elongated form. It is when in this condition that the cells and basement tissue may be restored to the appearance of cartilage by the use of hydrochloric acid. Occasionally, however, a cell becomes converted into a well-developed lacuna, and near the ordinary bone the cells may be seen in more or less advanced stages towards their conversion (Plate VII. fig. 17).

In the ossified cartilage, when the tissue attains a considerable thickness, broad and ill-defined lines or bands of opacity may generally be found running parallel with the articular surface, and giving a stratified character to the part in which they are situated, as shown in fig. 17 *b*. When seen by transmitted light, these lines appear of

* Dr. QUAIN's Anatomy, fifth edition, by Mr. QUAIN and Dr. SHARPEY, part ii. page 158. "In the slow growth of bone which encroaches on the attached surface of articular cartilage, the ossification would almost seem to be produced merely by the impregnation of the cartilaginous matrix with earthy matter (corresponding with the first step of the ordinary process); and in this case, the cells and clusters of cells being surrounded by calcified matrix, may remain as little vacuities or lacunæ in the bone; but this as well as the formation of lacunæ in the crusta petrosa of the teeth, and the production of adventitious bony deposits in different textures, requires further investigation."

† KÖLLIKER, page 318, *oper. cit.*

a deep rich brown colour, and as if possessed of a much higher degree of granularity than the surrounding parts. The cells of the tissue are not uncommonly surrounded by a similar granular condition of the matrix. This state of granularity is most conspicuous near the bone, and less so near the cartilage, where the tissue becomes clear and transparent. The ossified cartilage is generally separated by a well-marked line from the subjacent bone. Exceptions to this, however, are not wanting, where the two pass, the one into the other, by insensible gradations. The bone at the line of junction is usually advanced into the ossified cartilage by rounded projections of variable size; some of which reach nearly to the surface, while others are situated at some little depth. From this arrangement the articular bone is necessarily irregular in quantity. In one part it will dip to a considerable depth into the bone, while at another and perhaps contiguous part it will form but a thin layer. The external or articular surface is but slightly affected by the irregularities of the surface attached to the bone; on the contrary, it presents an even surface, on which the articular cartilage is placed in a uniform layer.

The absence of Haversian canals, and the unfrequency of lacunæ with canaliculi in the articular bone, renders this tissue much less porous than ordinary bone, a condition which probably contributes to its strength, and to the strength of the part in which it occurs.

In the presence of this peculiar form of tissue at the articular extremities of bones we may perceive a striking instance of design.

It would appear that the articular cartilage must rest upon a firm and uniform surface, otherwise it would, under pressure, yield unequally, and the joint would probably be but imperfect in its action. Circumferential laminæ are developed only on free surfaces, and do not present there a very level outer surface. A surface formed by Haversian systems would be irregularly fluted or nodulated, like that beneath the calcified cartilage. Neither of those forms of development, then, would effect a condition of surface similar to that attained by the ossified cartilage. A careful consideration of the foregoing facts will, we think, lead to the conviction, that the presence of ossified cartilage as a basis for articular cartilage must not be regarded simply as the result of a slowly progressing ossification of a tissue prone to ossify; neither must it be regarded as an imperfectly developed tissue in which the formative process was arrested before the part had been perfected*; but it must be regarded as a constant element in the osseous system, having its special use, and necessary to the perfect organization of the skeleton in the higher forms of Vertebrata.

Ossified Lacunal Cells.—In addition to the parts already described, the authors have found a condition of bone which has hitherto escaped observation, or if seen, has not been recognized as a form of osseous tissue. The bones of aged people not unfrequently become extremely light and spongy, readily break, and from the diminished amount of compact tissue, may in the case of the flat bones, such as

* Kölliker, *oper. cit.* page 318, speaks of this tissue as imperfectly formed bone-substance.

those of the pelvis, be indented by firm pressure with the finger. Such bones, after maceration, contain within the spaces enclosed by the cancelli, a white powder, which readily falls out if the bone be broken. If a little of this powder be mounted in Canada balsam, and placed in the field of the microscope, the observer will see that it is mainly composed of large nucleated cells, some of which are detached, others united into masses.

The isolated cells have a spherical or oval form, and appear to consist of a granular nucleus surrounded by a very thick cell-wall, external to which we commonly find an aggregation of granular matter, indefinite in amount and presenting a ragged outline (Plate VII. fig. 15). The cells which are united into masses are connected by this granular matter, or ossified blastema, as it might perhaps be called. The cells themselves are similar to the loose ones, excepting that in some cases their character is rendered more apparent by the nucleus assuming the form of a lacuna. If a section of the bone be examined, similar cells will be found adherent to the walls of the Haversian canals, with the canaliculi of contiguous lacunæ advancing into them, while the nuclei of the adherent cells are assuming the form of lacunæ and throwing out canaliculi.

Again, in the substance of the bone, the outline of the formative cells, similar in size and shape to the loose ones, may be in places recognized, having lacunæ and canaliculi as their centres. The recognition of these ossified cells in their isolated state will be followed by the observation of similar cells occupying the Haversian canals and cancellar spaces in the majority of microscopic preparations of adult bone (Plate VI. fig. 5 *a*); and the same may sometimes be seen on the outer surface of bone (Plate VII. fig. 18). The appearance of the cells is, however, liable to be modified by the various circumstances which operate upon growing bone, such as the presence of a tendon, or of a large pulsating vessel, or in fact, by pressure from any cause. Thus if situated in the immediate neighbourhood of a tendon, they assume an elongated form; while on the other hand they may be flattened by pressure.

It has been thought desirable to describe the ossified lacunal cells at this place, on account of their frequent occurrence in adult bone (Plate VI. fig. 5 *a*, and Plate VII. figs. 16 and 18).

Bone Tissue.—Hitherto we have confined our description to the forms in which the bone substance is arranged, as into laminæ, Haversian systems, &c. We have now to consider the ultimate structure of the tissue itself. But little has been said upon this point until within the last ten years. In the 'Physiological Anatomy' of Dr. Todd and Mr. Bowman*, it is stated that bone is made up of an aggregation of granules in a scarcely distinguishable matrix. Latterly, other views have been proposed. Dr. Sharpey has advanced the hypothesis, that although the bone developed in cartilage is at one period granular†, a reticulate fibrous arrangement of the elements

* Dr. Todd and Mr. Bowman, Physiological Anatomy, page 108.

† Dr. Quain's Anatomy, edited by Mr. Quain and Dr. Sharpey, page 157. "The primary osseous matter forming the original thin walls of the areolæ is, as Mr. Tomes observes, decidedly granular, and has a

of the tissue takes its place, and must be regarded as the general condition of bone*. Dr. SHARPEY, when he formed this opinion, had directed his attention principally to thin fragments torn from the surface of bone macerated in hydrochloric acid. The authors have seen the appearance both in decalcified bone, and in sections which have not been chemically treated; but they believe the fibrous appearance to be an optical effect produced by the canaliculi and granules when the light is unequally distributed, or the object-glass in bad adjustment. It will be shown in the subsequent details, that the appearance can be produced and dispelled at pleasure by alterations in the direction of the transmitted light. If thin sections of bone are seen by transmitted light (passing through in the axis of the microscope,) the tissue will appear either granular or structureless, and in the laminæ alternations of granular and structureless parts will be seen. But if the light be allowed to pass in one direction only, and with considerable obliquity through the specimen, then the appearance of extremely minute fibres will present itself; and this not only in adult bone, but in the isolated cells of old and in developing young bone. They are most strongly marked over the lacunæ; to which, and to the canaliculi, a confused and broken outline is given. The fibres appear as though arranged in series of short and broken lengths, parallel, and without plaiting. If the specimen be a little out of focus there will be an appearance of reticulated fibres marked by

dark appearance; the subsequent or secondary deposit, on the other hand, is quite transparent, and of a uniform and homogeneous aspect, without obvious granules. This begins to cover the granular bone a very short distance (about the $\frac{1}{10}$th of an inch) below the surface of ossification, and, as already stated, increases further down. The lacunæ first appear in this deposit; there are none in the primary granular bone. In what further regards the nature and formation of the secondary deposit, my own observations lead me to differ considerably from the views of Mr. TOMES. He supposes that it is formed of cells which become impregnated with earthy matter,—the cartilage cells in the first instance, and afterwards the cells newly formed in the blastema. Now although certain appearances render it not improbable that there may be a layer of flattened and calcified cells next to the surface of the granular bone, I am nevertheless disposed to think that the subsequent and chief part of the deposit results from the calcification of successive layers of fibres generated in the blastema, and possibly derived from the granular cells, some cells being perhaps also involved along with the fibres, as in the ossification of the flat bones of the cranium: in short, it appears to me that the deposit in question is formed after the manner of intramembranous ossification already described (page 150). I infer that such is the process from the structure of the layers, for they are made up of fine reticulated fibres like the lamellæ of perfect bone shown at page 143."

* On this point KÖLLIKER, *oper. cit.* p. 289, observes, "Die Grundsubstanz der Knochen besteht nach SHARPEY und HASSALL aus einem Netzwerk feiner Fasern mit rhombischen Maschen, von welchen Fasern ich weder an frischen, noch an mit Reagentien behandelten Knochen eine Spur habe entdecken können. Was ARNOLD neulich Primitiv-fasern der Knochen nennt, sind, wie seine Abbildungen lehren, nur die Granula der Grundsubstanz, an denen er eine lineare Aneinanderreihung zu erkennen glaubt, und seine Querstreifen auf Flächenschnitten, und radiären Linien auf Querschliffen, wenigstens die letzteren sicher, nichts als die Auslaüfer der Knochenhöhlen. Sollten durch irgend ein Reagens in dem Knochengewebe deutliche Fibrillen nachgewiesen werden können, was mir aber noch nicht gelungen ist, so könnten dieselben wohl keine anderen sein, als diejenigen, welche in ossificirenden Knorpel das streifige Ansehen bewirken und die von SHARPEY und mir bei der Knochenbildung aus dem Periost beschriebenen."

nebulous outlines. On the other hand, if we have light passing from all sides obliquely through the preparation, that is, if the object be illuminated by a hollow cone of light, in the manner obtainable by Mr. GILLETT's arrangement of achromatic condenser, or by rendering opake the centre of the lower lens of the ordinary achromatic condenser, the fibres disappear, and we see in their place a granular tissue, with a tendency here and there to a linear arrangement of the granules, and the lacunæ and canaliculi clear and distinct, when well in focus, but with a fibre-like nebulosity when slightly out of focus, especially in those parts where the latter run obliquely through the specimen. This is more especially the case where the canaliculi are filled with fluid, or where they have become solid, a condition very common in the bones of old subjects. Indeed, in many specimens where the bone is not highly developed, a fibrous appearance at once strikes the eye, and it is only on careful examination of the surface of the section that the illusion is dispelled by the orifices of the canaliculi appearing at the termination of the apparent fibres. Amongst a great many examples the authors have not seen an instance in which the fibrous appearance could not be traced to canaliculi, this effect being often increased by the presence of granules. If parallel dentinal tubes be viewed by a side light, in the manner we have described, each tube will throw two or three strong nebulous lines, which might be mistaken for fibres; and if tubes cut transversly be inspected in a similar manner, each will appear to have several concentric lines extending half round it on the side opposite to that from which the light proceeds.

That the presence of granules imbedded in a less refractive tissue may, when viewed by a side light, give an appearance of fibres, is shown on an examination of pus-globules under similar circumstances, when each globule will seem to have a striated surface; and that slightly rounded prominences will produce a like effect is shown in the case of some species of *Navicula*. The surface of these latter objects is marked by rows of slight prominences, which, when the light is oblique and passes through the specimen from one point only, appear as lines or fibres, the direction of which will change with alteration in the direction of the light; that is to say, shadows will extend from one eminence to another in the opposite direction to that from which the light enters. If we examine the projecting spiculæ of bone forming in temporary cartilage under corresponding conditions as regards light, a similar fibrous appearance will be developed.

Under these circumstances the authors are forced to the conclusion that bone substance, instead of being made up of minute reticulate fibres, is composed of granules or granular cells, imbedded in a more or less clear homogeneous or subgranular matrix. This subject will receive further elucidation under the head of development. These views are supported by the appearances presented not only in developing bone of young subjects, but also in the bone of adults.

Thus as regards the basement homogeneous tissue, it will be found that where lamination is highly developed, the laminæ have a transparent and structureless, and

a more opake and granular part, to which the former appears to be the matrix. The peripheral lamina of the Haversian systems is generally clear and free from granularity, and the internal lamina sometimes presents a similar structureless appearance. The matter which fills up the Haversian systems in the full-grown antlers of the Cervidæ, affords another and a very striking example of transparent structureless osseous tissue, which in this instance is the more distinct from the absence of canaliculi in its substance. Then, again, we have another instance in the clear tissue which is sometimes found between the superficial Haversian systems of ordinary bone. It has already been described as a non-laminated element found on the *surface* of certain bones. In the instances already cited, and no doubt in many others which may be found in the skeletons of the lower vertebrata, we have bone tissue without obvious granularity and without obvious structure, and although it forms but a small part of the general mass, yet from its constant presence at all ages and in all subjects, it must be regarded as an integral and normal part of mammalian bone. The granular condition of bone tissue is tolerably obvious in all preparations, though it is much more strongly marked in some specimens than in others. The amount of the component granules varies in different parts of the same specimen, and in specimens taken from different parts of the skeleton. Thus in one situation we may see laminæ with a highly granular part gradually merging into a transparent tissue, while in another the laminæ may be granular throughout. Again in young bone developed in cartilage, the part between the cells becomes highly granular; fragments of which may be found in certain adult bones, as in the petrous portion of the temporal bone (Plate VII. fig. 16 *b*). Bone near the articular surface frequently presents a well-marked granularity. Whether the granular and the transparent parts of bone contain different relative amounts of phosphate of lime is a question yet to be decided.

Development of Bone.—Temporary cartilage, when it first appears in the embryo, consists of an aggregation of closely packed nucleated cells, which in the process of growth become separated by the development of a tissue external to them, usually designated the hyaline tissue of cartilage. At this stage of growth we have a granular cell occupying a cavity in the hyaline tissue; at a previous period the granular cell was inclosed by an outer cell-wall, to which it formed the nucleus, but now the cell-wall has merged into the hyaline tissue, from which it can no longer be distinguished, while the granular cell contains itself one or more nuclei. In making sections of cartilage many of these granular cells escape from their cavities in the hyaline tissue, and may be seen detached and floating about in the field of the microscope. Some little confusion of terms has arisen in connexion with this part of the subject. The granular cells are not unfrequently described under the name of cartilage-nuclei containing nucleoli, while in fact they are cells capable of separation from the matrix, and are at one period the only recognisable cartilage cells. They occur singly or in groups, more frequently however two or three are extended in a line. It is proposed in the present communication to call

these bodies *granular cartilage cells*, as distinguished from a form which the cells assume previous to ossification. Cartilage previous to its conversion into bone undergoes a rapid growth, which takes place principally in the direction of the long axis of the future bone. Each granular cell becomes divided into two by segmentation transverse to the line of ossific advance. These are again divided, and the process repeated from time to time, till in the place of a single granular cell we have a long line of cells extending from the unchanged cartilage to the point where ossification has taken place. Contemporaneously with this development of lines of cells, other changes are going on in the individual cells composing them. If we examine those situated near the advancing bone, it will be observed that the granular cells have enlarged, have become separated from each other by wide intervals, and that each has become invested with a thick pellucid cell-wall (Plate VIII. figs. 19 and 20). The increase in the size of the cells has occurred at the expense of the hyaline tissue, which, at those points where the rounded cells approach each other, is reduced to a thin film, although in the intervals left by the packing of the uncompressed cells it exists to a considerable amount. Here then we have a matrix containing cartilage cells composed of an outer pellucid coat, within which is a granular cell containing central nuclei, a cell consisting of three distinct parts. The nucleus existed previous to the segmentation of the granular cell, but the outer wall is the product of a subsequent development. It will be observed that growth is effected by two modes; first, by the increase of the number of the cells; and, secondly, by the increase of their size individually.

While these changes are going on for lengthening the shaft of a long bone, cells are being added by a somewhat similar process of division to the surface, so as to increase the diameter of the cartilage. For the development of the epiphysis the cells become multiplied on a similar principle, but instead of occurring in lines they are accumulated in oval or rounded groups*.

From this general view of the subject we will now proceed to consider in detail those conditions of cartilage which precede and prepare for its conversion into bone. These phenomena may be conveniently examined in the cartilage which connects the diaphysis and epiphysis of long bones, and we may take those of a lamb or calf, as they present the same conditions as are found in the human subject, and have the advantage over those of other domestic animals of being readily obtainable at all times without the necessity of destroying the animal for the sole purpose of physiological investigation.

At that point in the cartilage where the linear arrangement of cells commences, several of these bodies lie side by side in the same column, but by following the line downwards towards the advancing bone, it will be seen that the column usually divides, forming two or three distinct lines, in each of which the cells are arranged

* Previous to the ossification of the epiphysis the cartilage at the heads of the bone is increased in its bulk from additions to the surface, by a process somewhat similar to that through which the growth of bone is effected. This process will be described when the latter subject is considered.

in single file. It does not appear that the number of cells entering into the formation of a series is at all limited; hence the lines or columns vary in length. Neither does it appear that the consecutive lines are placed, as a rule, end to end, so as to form one long continuous straight line by the junction of several shorter ones. On the contrary, each series is complete in itself, and is generally placed a little to the one or other side of those above and below it. We have in fact interrupted lines of cells, each line the offspring of a single cell, the outer walls of which have merged into the intercellular or hyaline tissue.

When the destined number of cells forming a linear series has been developed, each cell becomes itself a centre of growth. The granular cell enlarges, together with its nucleus, and becomes invested with a cell-wall. In examining a line of these bodies extending from the forming bone of the diaphysis, we shall see them in various degrees of forwardness. Thus, if attention be directed to the end of the line furthest from the bone, the cells will be found small in size, granular, and with a perceptible nucleus, but without an outer wall, distinguishable from the hyaline substance, which is abundant between the contiguous lines, but small in quantity between the cells composing the lines. But if the other end of the line be examined, very different conditions will be observed. The granular cells will be seen to have become rounded in form, to have increased to three times their original bulk, and to possess well-marked circular nuclei; in addition to which each granular cell will have acquired a thick pellucid outer wall, while the hyaline tissue between contiguous lines of cells will have dwindled down to a thin film, excepting in those parts where spaces are necessarily left in the approximation of spherical bodies (Plate VI. figs. 19, 20). The abundance of the hyaline tissue in the earlier condition of cartilage, affords space for the development of the cells in the breadth of the bone, but in the direction of the length of the bone we find but little of that tissue, yet each component cell of the almost innumerable lines of cells that exist, even in a bone of small size, is itself a centre of growth. At the osseous end of a line, a single cell occupies more space than four or five at the opposite extremity; and as in each situation the cells are imbedded in hyaline tissue, it is evident that there is a concurrent growth of the latter throughout each line of cells, and also of the cells and hyaline tissue in the breadth of the cartilage. But for this provision of nature, cells would grow at the cost of those in their neighbourhood, a condition which obtains wherever space for a secondary development of bone is required, a description of which will follow in the subsequent pages of this paper. Then, again, had we concurrent growth in each cell of a series without a similar growth in all the other series, throughout the breadth of the bone, the growing series would encroach upon the cartilage in which the linear arrangement had not commenced, and ultimately unite by osseous tissue the epiphysis and diaphysis before the bone had acquired its normal length. And supposing concurrent growth to take place over the one-half of the breadth of a bone and not in the other, the bone would become curved and the limb distorted.

We have traced in temporary cartilage those changes which occur preparatory to its conversion into bone: it now remains for the authors to describe the results of their researches on the mode in which that conversion is effected, and concerning which there hitherto has been a great diversity of opinion.

Preceding ossific deposit, the intercolumnar tissue, which may not only be seen between the columns of cells, but also passing more or less perfectly between the individual cells, becomes in some cases slightly fibrous in appearance, and of a light brown colour; this condition speedily gives way to a highly granular state; in fact it has become bone, and encloses, in osseous cavities or crypts, the cartilage cells. For reasons which will hereafter be sufficiently obvious, we shall in future call these lacunal cells. If thin sections be made with a very sharp knife through ossifying cartilage, and placed in water or albumen under the quarter or eighth object-glass, we shall occasionally find lacunal cells which have escaped from their osseous crypts, floating loose in the fluid, and offering a favourable opportunity for the examination of their characters. It may then be seen that the thick pellucid outer investment has become granular, and that the enclosed granular cell has lost its regular outline, and become angular or ragged, while the nucleus has become obscured by the changes in the more external parts of the cell, an early stage of which is seen in Plate VIII. fig. 19 and 22 *a*. Such are the appearances presented in some of the detached lacunal cells, but they may be seen in both earlier and later stages of development than that described. Thus instances may be found where the outer coat has only a few granules on the surface, in which case the granular cell may be seen more distinctly, and minute elongated processes traced, extending from its surface (Plate VIII. figs. 19 and 20). In a favourable section we sometimes find such a cell with its outer coat torn, exposing to full view the granular cell, with numerous and well-marked processes extending from it. Dr. SHARPEY kindly placed at the disposal of the authors the rickety bone of a child who died during the active condition of the disease. In this specimen granular cells with radiating processes can with great readiness be detached by tearing a thin section, for in this case cartilage assumed the arrangement of bone without the impregnation of earthy ingredients (Plate VIII. fig. 23)*.

The third condition, in which we may find isolated lacunal cells detached from the osseous crypts of the intercellular tissue, differs from those already described in their greater solidity. The whole mass has become highly granular, and the granular cell with its processes has united to the outer coat, so that the two can no longer be

* KÖLLIKER, *oper. cit.* at p. 360, describes accurately the formation of lacunæ from cartilage cells in a rickety bone, and although he has not observed the changes with equal distinctness in normal bone, appears to have satisfied himself that in the ossification of cartilage the cells of the latter become converted into lacunæ. M. KÖLLIKER does not however seem to have recognized the relation of the lacunal cells as such to the intercellular tissue, neither does he mention the fact that the granular cells with their long stellated processes can be separated from the investing cell-wall in the manner described in the text.

separated the one from the other, and are no longer to be recognized as distinct parts. If accidentally broken across, we see that they have a hollow centre, in fact, a lacuna; but when loose and entire, they appear as rounded dense masses, projecting from the surface of which we may not unfrequently detect a few short needle-like processes. Lacunal cells of the latter kind are not, however, very easily detached, for when they have advanced thus far in development, their union with ossified intercolumnar tissue is too strong to admit of ready separation; indeed, after this period their separation is impossible. It has been stated that the granular cells of cartilage previous to the formation of lacunal cells send out processes. There are, however, a certain number of granular cells that do not appear to undergo this change, but preserve their state of granulation and their external figure, and show the round nucleus even after they are surrounded by and imbedded in ossified tissue. Indeed, we may find perfectly ossified crypts of intercolumnar tissue at some little depth within the forming bone, containing several of these granular cells in an unaltered condition, and this without the cavities having been enlarged by absorption of their walls (Plate VIII. fig. 19 *d*). It is important to bear this point in mind, as it will subsequently be shown that similar granular cells lie loose in the large cavities formed by absorption, and that they are concerned in the formation of bone when that tissue is not preceded by ordinary cartilage.

If a section of developing bone, including a little of the cartilage, be dried, and mounted in Canada balsam, we shall be able to recognize, first the cartilage with the cells greatly contracted, then the ossified intercolumnar tissue full of little crypts, from which, in the process of drying, the lacunal cells have disappeared (Plate VIII. fig. 24 *a*); and lastly, we shall see bone in which ossified lacunal cells run in lines corresponding to the preceding lines of cartilage cells (fig. 24 *b*). The latter appearance is, however, interrupted by the presence of numerous large spaces produced by the absorption of both the intercolumnar tissue and the lacunal cells (fig. 24 *c*), the process for the removal of which commences concurrently with the impregnation of the lacunal cells with the earthy salt.

These conditions can be also very favourably observed in sections of the long bones of a fœtal lamb, taken previous to the commencement of ossification of the epiphysis, and examined in the liquor amnii; water will not answer as a substitute for this fluid, as the cartilage cells are speedily altered in character by its presence. And we may here observe that the examination of developing bone should be conducted on perfectly fresh subjects, and that care should be taken to keep the knives, glass, &c., which are used in preparing the sections, perfectly free from extraneous matter; otherwise the results will be unsatisfactory. Thus a small quantity of spirits of wine or of acid will produce changes of character in the specimen, and thereby lead the observer into an erroneous conception of the normal characters of the tissue.

Hitherto the authors of this communication have spoken principally of those appearances which are presented in sections made parallel with the advancing bone;

attention must now be directed to sections made across the bone, so as to cut transversely the lines of cartilage cells.

If, then, we take a thin section through the cartilage where ossification of the intercellular tissue is advancing, the following appearances will be seen. The intercellular tissue will present itself in the form of more or less perfect septa lying between and enclosing the lacunal cells, in such a manner as to produce a uniform pattern over the surface of the section (Plate VIII. fig. 20). On close inspection it will be seen that the intercellular tissue is granular, and that in each enclosure it encircles one or two lacunal cells, which in the latter case lie in contact, with the contiguous sides flattened, while the peripheral surface of the two form together a tolerably perfect circle in close contact with the intercellular tissue.

The lacunal cells are beautifully shown in the kind of section under consideration. Their circumference is becoming granular, and frequently may be seen as a perfect ring of granules in close contact with the intercellular tissue, while in the centre we see the granular cell with a well-defined nucleus, and with numerous rudimentary canaliculi, extending from the circumference of the inner cell towards the surface of the outer cell-wall. Where two cells lie in contact, the rudimentary canaliculi may sometimes be found running across from the one cell to the other. If after examining such sections as may be made with a knife, we take one through the bone immediately below the partially ossified cartilage, rendered thin by grinding, and mount it in Canada balsam, the various points described as existing in ossifying cartilage will be seen in that which has been converted into bone. Thus we shall see the intercellular tissue preserving its original form, and highly granular, and that while the outer walls of the lacunal cells have become calcified, the granular cells will have assumed the form of perfect lacunæ and canaliculi, the latter freely intercommunicating where the surface of the lacunal cells is in contact, but seldom extending into the ossified intercellular tissue. These conditions are shown in Plate VII. fig. 25.

The ossified lacunal cells, and the intercellular tissue which have existed in the temporary cartilage, and have there served their part in forming the skeleton of the fœtus, are destined to have but a short existence, for we find that no sooner is the bone formed than large spaces are produced by absorption. Whole lines of ossified lacunal cells with the enclosing intercellular tissue disappear, to be replaced by more or less perfectly developed Haversian systems, which also last but for a time, when they by a similar process are removed to give place to others, or to contribute to the formation of permanent cavities. It has been well stated by Dr. Sharpey, that the long bones of the fœtus are not equal in size to the medullary cavities of the corresponding bones of the adult. Hence as growth takes place, gradually comes the necessity for the removal of parts to make way for the development of others upon an enlarged scale.

It has been shown that primary bone, if we except two or three of the cranial bones, is merely calcified cartilage which has previously assumed the structural

arrangement of bone. It is proposed to restrict the term primary bone to tissue so formed, as it will be subsequently shown that the development of Haversian systems in the spaces formed in primary bone, is effected by processes similar to those which are concerned in the growth of bone generally, and in the extension of the flat cranial bones. Age and situation no doubt modify the conditions of growth, or development of secondary bone, as it may be called, but the processes in either case are alike.

Hence, in describing the manner in which a long bone increases in diameter, we shall in fact be describing the process by which a flat cranial bone is extended. Before however going to this point the authors will state the results of their observations on the subject of the absorption of bone, on that interesting and important process by which the Haversian spaces are formed out of the solid tissue of bone.

During the present winter it became necessary to remove a portion of the femur which protruded from a stump six weeks after the removal of the limb. From the medullary cavity a granulating mass projected and covered the surface of the bone left by the saw, and as the bone was rapidly wasting from the inner or medullary surface, we had in this specimen a favourable opportunity of examining the tissue which lay in immediate contact with the surface of the wasting bone. On cutting through this piece of femur in its length with a very fine jeweller's saw, it was found that a dense pale pink tissue lay in contact with the inner surface of the bone, which was hollowed with numerous minute cavities, into which the soft tissue accurately fitted, but from which it could be detached without tearing. The outer surface of the bone had been deprived of membrane many days before its removal from the limb.

The examination of the tissue thus closely applied to the fast wasting bone, offered as favourable an opportunity for learning something of the means by which absorption is effected as we could reasonably expect to obtain, the more so since the outer surface having been for some time exposed and covered only by dried periosteum, the actions had been confined to the inner surface of the bone. A careful examination showed that the surface of this tissue was composed of minutely granular nucleated cells, which lay in close and immediate contact with the bone, and increased in an exact ratio with its diminution. What the bone lost in bulk the cells gained, the cellular mass presenting a perfect cast of the surface of the bone, suggesting to the mind that the soft was growing at the cost of the hard tissue, or at all events that the former was instrumental in the removal of the latter. The cellular mass was tolerably vascular, but the vessels did not reach the surface in contact with the bone; hence they could not be regarded as having any immediate action in the process of absorption. Section of the bone showed that the medullary cavity had been greatly enlarged by absorption, and no doubt had sufficient time been allowed the femur at that part would have been reduced to a thin scale. A transverse section showed that in many, though not in all instances, the Haversian canals had been enlarged and rendered irregular in shape, but it was evident that the process of removal had been less active in this situation than on the medullary surface of the bone.

If we examine the fangs of temporary teeth when they are undergoing removal, similar states to those described as existing in the portion of femur will be found to obtain. A similar cellular mass will be seen to be closely applied to that surface of the tooth which is in process of removal, and the surface itself will present the characteristic emargination observed in the bone. When we connect these conditions with the fact that the nucleated cells which form the embryo have the power of appropriating the material which lies about them to the purpose of their own growth and their conversion into the various animal tissues, it is difficult to resist the belief that the cells which lie in contact with wasting bone and dentine, take up those tissues and use all or part of their element for the purposes of their own increase or multiplication, or else form a medium through which they are passed into the circulation. But as the process of absorption with concurrent development of cells is most active in primary bone where but few vessels exist, the former hypothesis seems the more probable. An objection may be raised to the supposition, that the bone is absorbed by the cells, on the ground of the density of the former; but it must be borne in mind, that as the density is gradually imparted to the bone through the agency of the adjoining soft parts, there seems no good reason for disbelieving that they may also be instrumental in its removal.

Growth of Bone.—Under this head will be described the extension of flat bones, the increase in the diameter of cylindrical bones, and the development of Haversian systems.

If the advancing edge of a parietal bone be taken either from a human fœtus or a fœtal lamb, and the pericranium and dura mater be carefully removed from their respective surfaces, we shall find the growing bone still invested with soft tissue both on the outer and inner surface, which is prolonged from the free edge. When examined under a favourable light this tissue will show differences of character in different parts, varying with the distance from the bone at which the observations are made. Thus, if attention be directed to the part furthest removed from the bone, it will be seen that the membrane-like mass is composed of oval cells with slight prolongations from the extremities, which are frequently arranged in the form of bands of fibrous tissue (Plate VIII. fig. 26). Dr. Sharpey has observed that the membrane into which the bone extends is like fibrous tissue in an early stage of development*, and this observation is strictly true when confined to the part indicated, but the analogy

* Mr. Quain and Dr. Sharpey, *oper. cit.* cxlix. and page clix. Dr. Sharpey says, "When further examined with a higher magnifying power, the tissue or membrane in which ossification is proceeding, appears to be made up of fibres and granular corpuscles, with a soft amorphous or faintly granular uniting matter. The fibres have the character of the white fibres, or rather fasciculi of the cellular or fibrous tissue, and are similarly affected by acetic acid. The corpuscles are for the most part true cells with an envelope and granular contents; some about the size of blood-particles, but many of them two or three times larger. In certain parts the fibres, but in most the corpuscles predominate, and on the whole the structure may be said to be not unlike that of fibrous tissue in an early stage of development." Kölliker, *oper. cit.* p. 289, confirms Dr. Sharpey's statement, but denies that a fibrous arrangement can be traced in formed bone.

ceases as we extend our examination towards the bone. Here in the place of cells with elongated processes, or cells arranged in fibre-like lines, we find cells aggregated into a mass, and so closely packed as to leave little room for intermediate tissue. The cells appear to have increased in size at the cost of the processes which existed at an earlier stage of development, and formed a bond of union between them. Everywhere about growing bone a careful examination will reveal cells attached to its surface, while the surface of the bone itself will present a series of similar bodies ossified (Plate IX. figs. 27, 28 and 29). To these we propose to give the name of *osteal cells*, as distinguished from lacunal and other cells.

In microscopic characters the osteal cells closely resemble the granular cells of temporary cartilage, so closely indeed, that the latter when detached from the cartilage could not well be distinguished from them. They are for the most part spherical or oval in form, and lie on the surface of the growing bone in a crowded mass, held together by an intervening and apparently structureless matrix (Plate IX. fig. 27 *b*). Here and there we find a cell which has accumulated about itself an outer investment of transparent tissue, and has in fact become developed into a lacunal cell destined to become a lacuna*. These points are illustrated in fig. 29 *b*.

The process of growth may be thus described. In the meshes of the fibrous tissue

* The various views which have been entertained regarding the formation of the lacunæ and canaliculi have been concisely stated by Dr. Sharpey, *oper. cit.* p. 158. He observes, that "they are generally supposed to be derived from the cells of the soft tissue involved in the ossification by some sort of metamorphosis which has been variously conceived. Some suppose that the cells become the lacuna and send out branches (like the pigment cells) to form the canaliculi (Schwann[1]). Others think that it is not the cell but its nucleus that undergoes this change, and that the substance of the nucleus is afterwards absorbed, leaving the lacuna (Todd and Bowman[2])." The nucleus described by Todd and Bowman is identical with that which in this communication is called the granular cell, and from which the authors have shown the lacuna is formed. "Henle[3] thinks that the lacuna is a cavity left in the centre of a cell which has been partially filled up by calcification, and that the canaliculi are branched passages, also left in consequence of the unequal deposition of the hard matter, as in the instance of the pore cells of plants." "It rather appears to me as if the lacunæ and canaliculi were little varieties left in the tissue during the deposition of the reticular fibres, as open figures are left out in the weaving of some artificial fabrics (but not within a cell, as Henle imagined), and that thus the apposition of the minute apertures existing between the reticulations of the lamellæ gives rise to the canaliculi." "At the same time it seems not unlikely that a cell or a cell-nucleus may originally lie in the lacuna or central cavity, and may perhaps determine the place of its formation." Hassall[4] agrees with Schwann, while Gerber[5] and Bruns[6] appear to hold the views of Todd and Bowman. With the exception of Dr. Sharpey, the above-named authorities may perhaps differ more in the use of terms than in matter of fact. The appearances represented in figs. 14 and 27 would at first view seem to justify the opinion expressed by Dr. Sharpey, but a careful examination of the tissue during its development, the unquestionable fact that in the development from cartilage the granular cell becomes converted into a lacuna, together with the circumstance that lacunal cells are frequently found in the Haversian canals and cancellated structure, especially in the bones of old subjects, and at times imbedded in the structure of the bone, have left no room for doubt in the authors' minds that the lacunæ are formed from special nucleated cells, in the manner described in the text.

[1] Mikroscopische Untersuchungen. [2] Physiological Anatomy. [3] Anatomie Générale.
[4] Microscopic Anatomy of the Human Body, p. 310. [5] Allgemeine Anatomie.

on the surface of the bone *osteal cells* are developed and gradually take its place; a few cells become developed into lacunal cells; the earthy salts are added, and concurrently lacunæ and canaliculi are formed; we then have bone presenting the usual characters of that tissue*. In bone developed in the foregoing manner, we find the canaliculi not merely extending to the surface of the cell-wall, or anastomosing with the canaliculi of lacunal cells lying in contact with it, but extending freely in all directions and passing through or amongst the ossified cells, and establishing rich plexuses of anastomosis. Indeed we see the boundary of the original lacunal cells only in those cases where the lacunæ have but few, or are entirely devoid of canaliculi. It would appear to be a law, to which there are few if any exceptions, that when anastomosis is established between adjoining lacunæ, the lacunal cells blend with the contiguous parts, and are no longer recognisable as distinct bodies. The process by which the cylindrical bones are increased in diameter is in all essential points similar to that described as pertaining to the growth of flat bones. Similar osteal and lacunal cells are present, but the relative amount of the matrix is greater; moreover the osteal cells have a disposition to assume a linear arrangement corresponding to the direction of the laminæ of the contiguous bone. In these lines the cells are placed so close to each other as to leave but little room for intervening tissue, but between the lines an appreciable amount may be recognized (Plate IX. fig. 31). This appearance however varies in different specimens. In one the cells predominate, in another the transparent tissue is the more abundant. Generally the younger the animal the greater will be the amount of the intervening transparent tissue, and the smaller the number of the osteal cells. But in all cases, whatever the age of the subject, or from whatever part of the skeleton the specimen be taken, the cells and the intermediate tissue become blended in the process of ossification, and the whole presents a uniform granular appearance, excepting in the instances in which lamination is strongly developed, or in those which have been noticed in the previous part of the paper. We frequently find portions of bone where the osteal cells, lacunal cells, and intermediate tissue are so perfectly fused together that neither can be recognized, but in their place we have a minutely granular mass, divisible only into lacunæ and canaliculi and the tissue in which they lie imbedded. In Plate IX. fig. 32, taken from the tibia of a fœtal lamb, the osteal and lacunal cells have become blended to a considerable extent, but without the

* When speaking of the growth of cartilage, it was stated that the bulk of that tissue at the epiphysis increased laterally by the division of the cells, but the fact that it also increased on the free surface of the greatly enlarged cartilaginous epiphysis of the fœtus by a process similar to that by which the diameter of bones is increased, was reserved to be described in connection with the latter subject. If a longitudinal section be taken from the epiphysis of a fœtal long bone, including some portion of the perichondrium, it will be seen that the cartilage passes gradually into a more or less fibrous tissue, which forms the exterior of the part. Amongst the fibres will be found numerous elongated cells, which on tracing the specimen inwards will be seen to be similar to the cartilage cells at and near the surface of the tissue, while the fibres will be seen to give way to or become converted into hyaline tissue, as shown in Plate IX. fig. 30, in which the cartilage is indicated at *a*, and the cells included in the fibrous tissue at *b*.

occurrence of lamination. The lamina which is represented at the margin is composed of still uncalcified cells. It shows the mode in which the undulating laminæ are formed. Fig. 33 also, taken from the fibula of a calf, shows ossified lacunal and osteal cells without any tendency to lamination.

The manner in which the Haversian spaces become gradually occupied by Haversian systems is peculiarly interesting. To obtain a good view of the process, it is necessary to make a transverse section of the developing systems. It may then be seen that osteal cells arrange themselves in single file within the Haversian space with intermediate lines of transparent tissue, and here and there a lacunal cell; the process commencing at the surface of the Haversian space, and extending gradually inwards till the system is completed. In fact the soft tissue takes the permanent form previous to the addition of the salts of bone, much in the same manner and to the same degree as occurs in temporary cartilage before the earthy ingredients are deposited. Lamination is nothing more than a definite linear arrangement of the osteal cells with their outlines permanently retained in the perfected bone; a character much more strongly marked in the bones of adult than in those of young animals.

In pursuing their inquiries into the growth of bone, the authors found it necessary to take sections of perfectly fresh bone and to examine them in albuminous fluid; spirits of wine, whether diluted or not, obscures the normal appearances, and water is not more favourable as a medium.

Sections permanently mounted in dilute spirit lose a good deal of their character; still the appearances are preserved with more or less of their original distinctness. Sections mounted in Canada balsam show some of the points remarkably well. For instance, the partially ossified osteal and lacunal cells are tolerably well preserved, but unfortunately those cells which have not received any of the indurating salts are represented only by a transparent mass, in which but little structure can be recognized; thus, the part *b* in fig. 32 would have appeared but as a transparent line had the specimen been mounted in Canada balsam. In addition to the necessity for care in the examination of osseous structures, under the most favourable circumstances, as regards the selection of specimens and the fluid used in their preparation, it is equally necessary to have the more recent appliances for the illumination of the objects.

Mr. Gillett's achromatic condenser, with what is called the white cloud illuminator, renders it very easy to demonstrate points which with the ordinary miscroscopic apparatus are shown with difficulty. It need not however be urged, that it is desirable in pursuing structural anatomy to avail ourselves of the most perfect instruments that can be obtained. It is proper that the authors should, before leaving this part of the subject, draw some comparison between the development of bone in cartilage and in the softer tissues.

Temporary cartilage, previous to the development of bone, affords a mechanical support and protection to the surrounding or enclosed softer tissues. These offices

could not be rendered by a mere aggregation of soft cells, but are efficiently performed by the dense intercellular substance, which forms so characteristic a feature of the cartilage. Hence in the mechanical function of cartilage the intercellular element of the tissue must be regarded as the most important.

A second, and scarcely less important purpose effected by temporary cartilage, is that of affording a medium for which a more solid tissue may be substituted, without the mechanical support being withdrawn from the adjoining parts during the process of change. It affords also a means by which the long bones are gradually increased in length, without any interference with the functions of the limb. These changes are brought about by the gradual increase in the number of the cartilage cells, at those parts only where ossification is about to commence, and by the conversion of the cells into lacunal cells, at the cost of the intercellular tissue, which, whilst its bulk is diminishing, becomes impregnated with the earthy salts; so that although the quantity is lessened, the strength of that which remains is increased. Now, in examining the process by which growing bones are enlarged, it must be borne in mind that the mechanical function of the cartilage is performed by the bone which has replaced it, and that no such office is required of the new tissue which is gradually adding to the bulk of the bone. The necessity for a dense intercellular tissue no longer exists. Hence we have an aggregation of osteal cells with so much only of intercellular tissue as will serve to connect them into a mass. A certain number of these cells, by additions to their exterior, become lacunal cells. We have then in the place of lacunal cells and dense intercolumnar tissue, lacunal and osteal cells united by a small and almost imperceptible amount of a semifluid intercellular medium; the relative proportions of these several parts varying a little with differences of age. Thus in aged subjects aggregations of lacunal cells may here and there be found with but few osteal cells and but little intercellular tissue, while in a young subject osteal cells will preponderate.

In all cases a direction may be given to the cells of a growing part, by their being in relation with the insertion of a tendon.

A consideration of the foregoing facts will, we think, lead to a conviction that the two different forms in which bone is developed, are designed to meet the requirements of the animal at different periods of life, and that bone developed by means of osteal and lacunal cells is the higher form of the tissue. In early embryonic life a soft cartilaginous skeleton is laid down, which is hard as compared with the surrounding parts, and capable of affording them the required amount of mechanical support. As the various tissues advance in development the cartilage increases in density by the elaboration of its hyaline tissue, and after awhile those changes occur which precede its conversion into bone. But in the bone so formed, it has been shown that the canaliculi anastomose only at those points where the lacunal cells come into contact (Plate VIII. fig. 25). In bone formed from osteal and lacunal cells, the anastomosis of the canaliculi prevails throughout the tissue, while the outline of the

formative cells is almost entirely lost in the general blending of the whole into a subgranular mass subject to lamination, in the manner already described.

It will therefore be in accordance with the preceding views, to regard the intercolumnar tissue present in primary bone, rather as an accessory element calculated to give support during the ossification of the lacunal cells, than as an integral and necessary element of osseous tissue; for it has been shown that it offers an obstruction to the anastomosis of the canaliculi, and that the lacunal cells preserve their outline so long as they are enclosed within it, instead of becoming lost in the surrounding tissue, as occurs in secondary bone. It must not, however, be forgotten that small patches of ossified intercolumnar tissue may here and there be found between the Haversian systems, even in the bone of old subjects (Plate VII. fig. 16); so that its presence in a small amount, (as accidentally left when the Haversian spaces are forming), is not incompatible with the normal condition of perfect bone.

It may also be stated in this place, that the undulating laminæ formed on the surface of growing bone, although for the most part removed to make way for Haversian systems, are also found here and there in small patches in the bones of adults.

The subject of absorption, as it relates to the removal of bone, has already been partly discussed, but something more remains to be said. Although the process of absorption has not, and probably cannot be seen in actual operation, yet a consideration of the relative position of the increasing and wasting parts, and of their conditions, will, in the authors' opinion, justify the conclusion that the bone is removed through the agency of cells.

In seeking to find the circumstances under which the absorption of bone takes place most rapidly, and to the greatest extent, the authors have been led to examine bones which had been placed in various conditions, both of health and disease. It has been already stated that bone developed in cartilage is speedily removed; but it does not seem that bone formed by osteal and lacunal cells is absorbed with equal rapidity, although in the course of a short time it not less surely disappears. This difference in the rate of absorption is probably the result of the vascularity and higher state of development of the latter tissue. In bone developed in cartilage Haversian spaces have to be formed before it can be permeated by vessels; hence in this tissue absorption proceeds rapidly, the process being established as soon as the bone is formed. In adult bone, when in a normal condition, we find here and there an Haversian space; but if a bone around which the soft parts are in a state of inflammation be examined, numerous Haversian spaces will be seen. If we examine the same bone in the neighbourhood of that part where the inflamed is merging into the healthy investing texture, we shall find new osseous matter in the process of deposition on the surface of the pre-existing bone. Examples of this may frequently be found in the vicinity of diseased joints.

We have here an instance of the development of new tissue, and the removal of a pre-existing one being set in operation, by what would appear to be a different degree

only of the same action. Hence a more particular examination of the cellular mass, by which bone appears to be absorbed in the one case and deposited in the other, naturally suggests itself, and attention has been directed to this point as frequently as favourable opportunities for observation have presented themselves. The differences, however, in microscopic characters between the two tissues, have not been so strongly marked, as to admit of any definite description being given, by which the one may, in all instances, be distinguished from the other, when removed from their natural positions, as is almost necessarily the case with regard to the absorbent cells, from the readiness with which they separate from the wasting bone (Plate IX. figs. 27 and 34).

Lacunal cells moreover will not be found in the absorbing tissue; but it is not easy to recognize them, even in the tissue from which bone is developing, as they are frequently obscured by the osteal cells; so that their presence, although a good ground of distinction, cannot in all instances be demonstrated. When, however, developmental cells are seen *in situ*, their character is readily distinguished. They are closely applied to the surface of the increasing bone, which loses the festooned and assumes an even outline, to which the osteal cells adhere.

The source from which the cells destined for effecting absorption arise is at present unknown to the authors, any further than that they arise in connection with soft tissues, the three situations in which they occur being beneath the periosteum or medullary membrane, or within an Haversian canal. These are no doubt the points from which the development of the cells starts, but the law which regulates their occurrence at one part rather than another, and gives to them their peculiar function, is at present unexplained. Neither is it more easy to understand why, at a particular period, the process of absorption is arrested and development of new tissue commences; the new bone may, for anything we have seen to the contrary, be formed from the same cells that have been concerned in the removal of the old. The organ by which the fangs of teeth are absorbed offers a very favourable object for examination.

This we find to commence within or beneath the periosteum which covers the fang of the tooth, and increases with the wasting of the tooth, until it comes in contact with the pulp, which then assumes a similar function and becomes an absorbing organ, increasing gradually in size, till, if the tooth be left undisturbed, but little of the crown remains excepting the enamel. If, when in this condition, the crown of the tooth be carefully removed, we shall see the absorbent papillæ projecting a little above the gum, firm in substance, and not disposed to bleed unless rudely handled. Within two or three days it becomes covered with epithelium, either by the extension of the epithelial membrane from the surrounding parts, or from a change in character in the superficial cells of the part itself*. Gradually the papilla loses its

* In the 26th volume of the Medico-Chirurgical Transactions, there is a short paper by Mr. Dalrymple, in which he describes a small tumour from the eyelid, consisting essentially of epithelial cells, in which the ordinary contents had been replaced by ossific matter.

distinctness of outline and merges into the surrounding gum, from which it can no longer be distinguished. Here then we have a second instance in which an absorbent tissue has its function finally suspended, and a new one substituted. In the place of increasing at the cost of pre-existing tissue, growth is suspended, and it unites with and assumes a similar office to that of the surrounding gum.

In conclusion, the authors may allude to an interesting fact, with reference to the subject of absorption, which has been recently observed by Mr. Stanley and subsequently by Mr. Bowman. In the treatment of ununited fracture, the practice has of late been successfully adopted of drilling cylindrical holes into the bone in the neighbourhood of the injury, and of driving in pegs of ivory, accurately fitted to the perforations, for the purpose of setting up action in their vicinity. These pegs, after remaining in the bone several weeks, have been removed, and have been found on inspection to present erosions similar to those which are seen on absorbing bone or tooth. In fact, they closely resemble the fangs of temporary teeth recently attacked by absorption. Mr. Bowman kindly placed at the disposal of the authors one of the pegs which had been used for this purpose, a section of which presents, at the parts eroded, in its microscopic characters, the usual emarginated outline so frequently alluded to in the foregoing pages. They have not however had the opportunity of investigating the condition of the tissues around the pegs; but it is exceedingly probable that absorption has in these cases been effected by processes similar to those which occur in the formation of Haversian spaces.

Explanation of the Plates.

PLATE VI.

Fig. 1. Transverse section of compact bone, showing the ordinary appearances. *a*. Haversian system. *b*. Interstitial laminæ. *c*. A new Haversian system within an older one, the Haversian canal obliterated by the development of a lacunal cell.

Fig. 2. Transverse section of compact bone, showing an Haversian space, with its characteristic emarginated outline.

Fig. 3. The same, from a less compact part of the bone, from a man aged fifty-six.

Fig. 4. Transverse section from the fibula of a child two years old, showing the general characters of bone in young subjects. *a*. Haversian space.

Fig. 5. Section of compact bone, showing several Haversian systems enclosed within a single series of laminæ. *a*. A lacunal cell attached to the surface of an Haversian canal.

Fig. 6. Section showing the characters of a new Haversian system, developed within an older one.

Fig. 7. An excentric Haversian system, illustrating the arrangement of the laminæ.

Fig. 8. *a*. Lamination of bone, as it appears under a low power. *b*. The same highly magnified, showing the lines of osteal cells and the intermediate transparent tissue.

PLATE VII.

Fig. 9. Transverse section of a stag's antler, after shedding, showing the transparent tissue which lines the Haversian canals.

Fig. 10. Section showing the circumferential laminæ, perforated by an Haversian system.

Fig. 11. Section showing the orifices of the canaliculi, with their parietes.

Fig. 12. Sections from rickety bone. *a*. Consolidated lacunæ. *b*. Lacunal cells, from which no canaliculi have proceeded.

Fig. 13. Section showing circumferential laminæ, with elongated canals passing amongst the lacunæ and canaliculi.

Fig. 14. Section of fossil bone, from the Wealden, supposed to be Pterodactyle, in which the nuclei have been preserved by fossilization.

Fig. 15. Ossified lacunal cells, from the spongy portion of a bone of an old subject.

Fig. 16. Section from the petrous portion of a temporal bone of an adult. *a*. Lacunal cells, containing lacunæ and canaliculi. *b*. Intercellular granular tissue, similar to that found in bone developed in cartilage.

Fig. 17. Section showing ossified articular cartilage. *a*. Lacuna developed from a cartilage cell. *b*. Lines of granules.

Fig. 18. Section from an incus in a subject aged seventy-five, showing osteal and lacunal cells on the surface.

PLATE VIII.

Fig. 19. Longitudinal section of ossifying temporary cartilage, showing—*a*. Ossified intercolumnar tissue. *b*. Lacunal cells. *c*. Granular cells in process of conversion into lacunæ. *d*. Lacunal cells imbedded in ossified intercolumnar tissue, without conversion into lacunæ.

Fig. 20. Transverse section of ossifying cartilage from femur of a child, fourteen days old. *a*. Intercolumnar tissue. *b*. Lacunal cell. *c*. Similar cell, with granular cell in process of conversion into a lacuna.

Fig. 21. Section from femur of same subject, taken a little way below the ossifying cartilage.

Fig. 22. A longitudinal section of new bone, a little further advanced than in fig. 19. *a*. A detached lacunal cell, showing the three parts of which these bodies are composed.

Fig. 23. From rickety bone. *a*. Lacunal cells. *b*. A detached granular cell in process of conversion into a lacuna.

Fig. 24. Longitudinal section of developing bone from the tibia of a calf, mounted in Canada balsam. *a*. Intercolumnar tissue, from which the lacunal cells have disappeared. *b*. Ossified intercolumnar tissue and lacunal cells. *c*. Space produced by absorption. *d*. Haversian system in process of formation.

Fig. 25. Transverse section of same, taken at level of *b* in fig. 24. *a*. Intercolumnar tissue. *b*. Ossified lacunal cell. *c*. Secondary bone.

Fig. 26. Arrangement of cells and fibres in the neighbourhood of developing parietal bone.

PLATE IX.

Fig. 27. Advancing spicula of bone, from parietal bone of fœtal lamb. *a*. Developed bone, showing its cellular character. *b*. Osteal cells arranged around the bone previous to their calcification.

Fig. 28. From the epiphysis of the long bone of a calf, showing osteal and lacunal cells.

Fig. 29. From the parietal of a human fœtus, showing osteal and lacunal cells, occupying the space betwixt two advancing spiculæ of bone.

Fig. 30. Longitudinal section of cartilage with epichondrium attached. *a*. The developed cartilage. *b*. Fibres of perichondrium, with cells of a similar character to those of the cartilage.

Fig. 31. Circumferential laminæ of human tibia, showing the manner in which the laminæ are developed from osteal cells. *b*. A compound cell, the origin? of the osteal cells.

Fig. 32. From the tibia of a fœtal lamb. *a*. Developed bone, showing the cellular character. *b*. Undulating lamina in process of development, and containing lacunal cells. *c*. Osteal cells, not yet arranged. At *d* is shown an Haversian space, enclosed in the advancing ossification, while at *e* the laminæ are approaching towards one another to enclose a space.

Fig. 33. From the fibula of a calf, showing growth on the external surface.

Fig. 34. From an inflamed femur, showing absorption, with the cells contained in the Haversian space.

V. *On the Periodic and Non-periodic Variations of the Temperature at Toronto in Canada, from* 1841 *to* 1852 *inclusive. By Colonel* Edward Sabine, *of the Royal Artillery, Treas. and V.P.R.S.*

Received January 20,—Read February 10, 1853.

The interest with which the comparison of the contemporaneous non-periodic variations of the temperature in Europe and America is regarded by meteorologists of great reputation, leads me to hope that the present communication may not be unacceptable to the Royal Society. The geographical situation of Toronto, both as respects latitude and inland position, renders it a very suitable locality for such comparison with stations in the middle parts of Europe, where similar observations have been made and where the conclusions to be derived from them are the subjects of active investigation. The years over which the observations at Toronto extended, 1841 to 1852 inclusive, were years of unusual meteorological activity in Europe; and the period of twelve years embraced by them is one of sufficient duration to supply a fair basis for generalisation on many of the problems which are now receiving the attention of meteorologists.

The observations at Toronto were made at the Magnetical and Meteorological Observatory at that station, by the detachment of the Royal Artillery by whom the duties of the observatory were carried on, and were under the direction of Captain Riddell, R.A., at the commencement of the observations, of Captain Younghusband, R.A., from February 1841 to the end of 1844, and of Captain Lefroy, R.A., from 1845 to 1852 inclusive. The latitude of the observatory is 43° 39′·6 N., and its longitude 79° 21′·5 west of Greenwich; the height above the surface of Lake Ontario is 108 feet, and above the Ocean about 342 feet.

From 1841 to 1844 inclusive, the thermometer was stationed beneath a roof on the outside of the north wall of the observatory. The height of the roof above the ground was about 7 feet, and three of the sides of the space which it covered (the observatory wall being the fourth side) were closed in by venetian-blind shutters descending from the roof to within 4 feet of the ground. The slope of the blinds of the shutters was such as to admit a free current of air whilst it completely screened the thermometer from rain. The shutters and the wall were coloured green, and the ground beneath was a grass-plat. The thermometer was fastened to two narrow strips of wood running horizontally from side to side of the thermometer shed, the ball being perfectly free, and about 6 inches higher than the bottom of the venetian blinds. The thermometer was read from the inside of the observatory through a

double window; its distance from the outer window being about 8 or 9 inches. From January 1845 to the end of 1852, the thermometer shed had the additional protection of a second roof and a second enclosure of venetian blinds on three of the sides, similar to those already described, and exterior to them at an interval of space from one to one and a half foot. The length of the exterior shutter on the northern side was 7 feet, and on the east and west sides 5 feet $4\frac{1}{2}$ inches. The thermometer was suspended as before with the ball perfectly free, and was read from the inside of the observatory through a window furnished with a sliding wooden shutter, which was kept closed, except at the times required for observation.

The same thermometer was employed throughout the whole period, excepting from March to December 1845, and in some few other occasional instances, in all of which corrections carefully ascertained were applied to give the values which would have been read by the thermometer usually employed. A comparison of this thermometer with a standard thermometer by Fastré of Paris, was made at all natural temperatures between April 1851 and February 1852, partly with the assistance of a telescope, and partly with the eye alone. The differences between the two thermometers at the several parts of the scale have been applied to all the observed temperatures before they were combined in the Table given in this paper. The standard thermometer by Fastré is divided *à l'échelle arbitraire* according to the method of Regnault. The zero-points were determined as follows:—

	0° Cent.	100° Cent.	For 1° Cent.
1851. Data furnished by M. Fastré	115·7	617·70	5·012
1851. By M. Izard and Capt. Lefroy at Paris	115·5	617·60	5·026

Re-examination at Toronto in 1852.

Freezing-point.		Boiling-point.		Barom. mm.	
January 13.	116·12	January 5.	614·60	743·055	617·76
14.	116·00	12.	616·55	755·136	617·45
22.	116·30	13.	614·00	740·866	617·57
28.	116·22*	28.	614·10	738·530	618·12
28.	116·10†				
				212° Fahr.=	617·72
	116·14=32° Fahr.				

whence 1° Cent.=5·0158; and 1° Fahr.=2·7865 divisions.

This last value has been employed in the comparison in preference to the original determination at Paris, from which however the difference is extremely slight.

During six years, *i. e.* from July 1, 1842 to June 30, 1848, the observations were made hourly,—Sundays, Christmas Days, and Good Fridays excepted, on which days no observations whatsoever were made. In the remaining six years, *i. e.* from January 1, 1841 to June 30, 1842, and from July 1, 1848 to December 31, 1852, the

* Before boiling. † After boiling.

same system was preserved in respect to *days*, but the *hours* of observation were less frequent. The series may consequently be divided into two portions, of which the first, or that containing the six years of hourly observation, will be first discussed.

The following Table exhibits the mean temperature at every hour in the different months on the average of the six years.

TABLE I.

Mean Temperature of the Air at Toronto, obtained by hourly observations from July 1, 1842 to June 30, 1848.

Toronto astronomical time.	Months.												Hourly means.
	Jan.	Feb.	March.	April.	May.	June	July.	August.	Sept.	October.	Nov.	Dec.	
Hours.													
0.	27°·83	27°·07	34°·00	47°·53	58°·80	66°·55	72°·85	72°·30	63°·52	49°·50	39°·57	29°·93	49°·12
1.	28·33	27·93	34·65	48·47	59·72	67·28	73·77	73·07	64·12	49·93	39·97	30·65	49·82
2.	28·60	28·33	35·22	48·85	60·07	67·70	74·62	73·65	64·52	50·28	40·05	30·80	50·22
3.	28·57	28·32	35·02	48·92	60·13	68·08	74·82	74·00	64·55	50·05	39·88	30·55	50·24
4.	28·05	27·77	34·55	48·53	60·08	68·32	74·83	73·85	64·33	49·32	38·98	29·90	49·88
5.	27·05	26·57	33·80	47·80	59·70	67·72	74·37	73·30	63·37	47·57	37·77	28·95	49·00
6.	26·23	25·12	32·12	46·00	57·95	66·42	72·93	71·40	60·70	45·52	36·95	28·25	47·47
7.	25·70	24·13	30·65	43·47	55·08	63·68	69·45	67·42	58·00	44·42	36·38	27·92	45·52
8.	25·38	23·28	29·68	41·88	52·37	60·38	65·25	64·50	56·72	43·68	36·07	27·53	43·89
9.	25·18	22·63	28·68	40·80	50·62	58·22	62·88	62·92	55·68	42·92	35·78	27·28	42·80
10.	24·80	22·08	28·03	40·03	49·65	56·88	61·65	61·90	54·62	42·17	35·43	26·98	42·02
11.	24·48	21·57	27·38	39·53	48·73	55·92	60·47	61·10	53·98	41·50	35·08	26·87	41·38
12.	23·80	21·45	27·33	39·37	47·88	55·37	59·45	60·30	53·63	40·95	34·42	26·53	40·87
13.	23·33	21·07	26·85	38·62	47·02	54·68	58·58	59·65	53·02	40·35	34·13	25·95	40·27
14.	23·25	20·73	26·47	37·95	46·18	53·98	58·02	58·97	52·43	40·03	33·85	25·58	39·79
15.	23·10	20·30	26·18	37·75	45·47	53·20	57·30	58·30	51·97	39·87	33·53	25·45	39·37
16.	23·00	20·00	25·80	37·32	45·00	52·63	56·67	57·92	51·38	39·57	33·37	25·42	39·01
17.	22·82	19·65	25·28	36·95	45·05	52·82	56·62	57·73	50·75	39·40	33·48	25·40	38·83
18.	23·55	19·08	25·00	37·08	47·50	55·47	59·83	59·18	51·43	39·62	33·75	24·98	39·71
19.	23·45	18·95	25·87	39·37	50·48	58·28	63·50	62·15	53·98	40·37	33·75	24·82	41·25
20.	23·68	19·97	27·85	41·62	52·70	60·62	66·10	65·42	56·73	42·62	34·80	25·25	43·11
21.	24·65	22·27	30·02	43·60	55·02	62·50	68·30	67·92	59·15	45·30	36·33	26·43	45·12
22.	25·88	24·28	31·75	45·12	56·72	64·17	70·00	69·90	61·12	47·23	37·77	27·88	46·82
23.	27·05	25·87	32·98	46·50	57·85	65·45	71·55	71·35	62·55	48·60	38·78	29·12	48·14
Monthly means.	25·32	23·27	29·80	42·63	52·91	60·68	65·99	65·76	57·59	44·20	36·24	27·44	44·32

The hourly observations from which this Table is formed will be found in full in the volumes of the Magnetical and Meteorological Observations at the British Colonial Obervatories, of which Toronto was one.

The temperature at any hour, and on any day of the year, corresponding to the mean values obtained in the six years and shown in Table I., may be computed from them by means of BESSEL's well-known interpolation-formula*, which may be thus written for the purpose:—

$$t_a = A_0 + A_1 \cos a + B_1 \sin a + A_2 \cos 2a + B_2 \sin 2a + A_3 \cos 3a + B_3 \sin 3a + A_4 \cos 4a + B_4 \sin 4a + A_5 \cos 5a + B_5 \sin 5a + A_6 \cos 6a,$$

* Astron. Nach. No. 136.

in which t_x is the temperature on x the required day, A_0 the mean temperature of the year at the hour required, $a = n \times 30°$, n denoting the number of months and parts of a month between January 15 and x, and A_1, A_2, ... A_6, B_1, B_2, ... B_6, constants derived from the values in Table I. by the method of least squares.

The constants for each of the hours, and for the mean temperature, derived from the six years of hourly observation, are as follows:—

TABLE II.

Constants for the calculation of the Temperature on the several Days and Hours from the Mean Monthly Values in six years.

Toronto astronomical time.	A_0.	A_1.	B_1.	A_2.	B_2.	A_3.	B_3.	A_4.	B_4.	A_5.	B_5.	A_6.
Hours.	°	°	°	°	°	°	°	°	°	°	°	°
0.	49·12	−23·38	−2·53	+0·60	+0·29	+0·62	−1·11	+0·31	+0·54	+0·25	+0·44	+0·31
1.	49·82	−23·48	−2·35	+0·65	+0·31	+0·63	−1·17	+0·30	+0·57	+0·13	+0·45	+0·27
2.	50·22	−23·65	−2·28	+0·73	+0·45	+0·55	−1·16	+0·36	+0·56	+0·09	+0·40	+0·29
3.	50·24	−23·87	−2·21	+0·85	+0·47	+0·59	−1·17	+0·35	+0·60	+0·15	+0·47	+0·25
4.	49·88	−24·23	−2·02	+1·00	+0·46	+0·68	−1·14	+0·31	+0·52	+0·16	+0·48	+0·26
5.	49·00	−24·52	−1·73	−1·17	+0·42	+0·70	−1·36	+0·20	+0·50	+0·16	+0·48	+0·35
6.	47·47	−24·10	−1·69	+1·56	−0·03	+0·48	−1·43	+0·21	+0·57	+0·27	+0·50	+0·35
7.	45·52	−22·54	−2·03	+1·46	−0·41	+0·38	−1·10	+0·23	+0·40	+0·28	+0·46	+0·35
8.	43·89	−20·95	−2·55	+0·91	−0·31	+0·58	−1·09	+0·15	+0·27	+0·43	+0·55	+0·35
9.	42·80	−20·05	−2·89	+0·75	−0·29	+0·69	−1·20	+0·15	+0·30	+0·51	+0·62	+0·34
10.	42·02	−19·61	−2·97	+0·72	−0·33	+0·66	−1·30	+0·14	+0·37	+0·52	+0·60	+0·34
11.	41·38	−19·25	−3·07	+0·68	−0·37	+0·71	−1·42	+0·11	+0·34	+0·55	+0·67	+0·30
12.	40·87	−19·02	−2·93	+0·52	−0·21	+0·68	−1·40	+0·02	+0·17	+0·51	+0·76	+0·21
13.	40·27	−18·84	−3·03	+0·52	−0·17	+0·63	−1·35	−0·05	+0·20	+0·58	+0·81	+0·22
14.	39·79	−18·60	−3·13	+0·58	−0·14	+0·59	−1·29	+0·02	+0·18	+0·63	+0·80	+0·25
15.	39·37	−18·38	−3·20	+0·47	−0·13	+0·59	−1·35	+0·14	+0·11	+0·65	+0·79	+0·22
16.	39·01	−18·11	−3·28	+0·50	−0·19	+0·59	−1·41	+0·13	+0·15	+0·69	+0·75	+0·20
17.	38·83	−18·17	−3·30	+0·60	−0·48	+0·54	−1·37	+0·12	+0·24	+0·73	+0·70	+0·17
18.	39·71	−19·58	−3·05	+1·20	−1·01	+0·65	−1·18	+0·31	+0·38	+0·79	+0·61	+0·47
19.	41·25	−21·48	−2·62	+1·21	−0·92	+0·80	−1·46	+0·43	+0·34	+0·65	+0·66	+0·59
20.	43·11	−22·63	−2·60	+0·85	−0·49	+0·73	−1·51	+0·39	+0·35	+0·70	+0·58	+0·53
21.	45·12	−23·05	−2·59	+0·56	−0·13	+0·69	−1·31	+0·34	+0·50	+0·53	+0·42	+0·45
22.	46·82	−23·20	−2·63	+0·50	+0·07	+0·70	−1·20	+0·24	+0·54	+0·44	+0·37	+0·39
23.	48·14	−23·28	−2·63	+0·55	+0·22	+0·69	−1·17	+0·29	+0·54	+0·34	+0·40	+0·32
Mean of the 24 hours.	44·32	−21·41	−2·64	+0·80	−0·12	+0·63	−1·28	+0·22	+0·38	+0·45	+0·58	+0·32

From the temperatures computed by the formula with the constants in Table II., corrections have been obtained to the mean temperature of the day for each of the hours of observation throughout the year, to be employed whenever a less onerous system than that of hourly or two-hourly (equidistant) observation is adopted, as was the case in the second period (also of six years) at Toronto. Table III. exhibits these corrections for every hour on every fifth day throughout the year; the corrections on the intermediate days admitting of easy interpolation. The corrections are additive when in the larger character, and subtractive when in the smaller.

TABLE III.

Corrections for every Fifth Day of the Year, to be applied to the Temperature observed at Toronto at any of the hours of Mean Astronomical Time, in order to give the Mean Temperature of the Day.

First Part, January to June. The corrections in the smaller type are subtractive; in the larger type additive.

Days of the month.	Hours of Mean Astronomical Time.																								
	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
	Subtractive.									Additive.													Subtractive.	
January. 5	2·3	2·8	3·1	3·0	2·4	1·5	0·7	0·4	0·0	0·1	0·5	0·7	1·4	1·9	2·1	2·1	2·2	2·3	1·8	1·9	1·6	0·7	0·5	1·6
10	2·4	2·9	3·1	3·1	2·5	1·6	0·8	0·2	0·0	0·1	0·5	0·8	1·5	2·0	2·1	2·2	2·3	2·4	1·7	1·8	1·6	0·7	0·5	1·7
15	2·5	3·0	3·3	3·2	2·7	1·7	0·9	0·4	0·1	0·1	0·5	0·8	1·5	2·0	2·1	2·2	2·3	2·5	1·8	1·9	1·6	0·7	0·6	1·7
20	2·6	3·1	3·4	3·4	2·9	1·9	0·9	0·4	0·0	0·2	0·6	1·0	1·6	2·0	2·1	2·3	2·4	2·7	2·0	2·1	1·8	0·7	0·6	1·8
25	2·8	3·4	3·7	3·8	3·3	2·1	1·2	0·4	0·0	0·2	0·7	1·1	1·6	2·0	2·1	2·4	2·6	2·8	2·3	2·5	2·1	0·8	0·6	1·9
30	3·0	3·7	4·0	4·1	3·6	2·4	1·3	0·5	0·0	0·4	0·8	1·2	1·7	2·0	2·2	2·5	2·7	3·0	2·8	3·0	2·5	0·9	0·6	2·0
February. 4	3·3	4·1	4·4	4·5	3·9	2·7	1·5	0·6	0·0	0·5	0·9	1·4	1·6	2·0	2·3	2·6	3·0	3·2	3·3	3·5	2·8	1·0	0·7	2·2
9	3·5	4·3	4·7	4·8	4·2	3·0	1·6	0·7	0·0	0·6	1·1	1·6	1·8	2·1	2·5	2·7	3·1	3·4	3·8	4·0	3·2	1·0	0·8	2·4
14	3·8	4·7	5·1	5·0	4·5	3·3	1·8	0·9	0·0	0·6	1·2	1·7	1·8	2·2	2·5	3·0	3·3	3·7	4·2	4·3	3·3	1·0	1·0	2·6
19	3·9	4·8	5·3	5·2	4·7	3·5	2·0	0·9	0·0	0·7	1·3	1·9	1·9	2·3	2·7	3·1	3·5	3·8	4·5	4·6	3·4	0·9	1·2	2·7
24	4·1	5·0	5·5	5·4	4·8	3·8	2·1	1·1	0·1	0·8	1·4	2·0	2·0	2·4	2·8	3·3	3·6	4·0	4·7	4·6	3·2	0·6	1·4	2·9
March. 1	4·2	4·9	5·5	5·3	4·8	3·9	2·2	1·0	0·1	0·9	1·5	2·1	2·1	2·6	2·9	3·5	3·8	4·2	4·8	4·5	3·0	0·4	1·6	3·0
6	4·2	5·0	5·5	5·3	4·8	3·9	2·3	1·0	0·0	0·9	1·6	2·2	2·3	2·7	3·1	3·5	3·8	4·3	4·8	4·4	2·7	0·2	1·7	3·1
11	4·2	4·9	5·5	5·2	4·8	3·9	2·3	0·9	0·0	1·1	1·7	2·4	2·4	2·9	3·2	3·6	3·9	4·4	4·8	4·2	2·3	0·0	1·8	3·1
16	4·2	4·8	5·4	5·2	4·7	4·0	2·3	0·8	0·1	1·1	1·8	2·4	2·5	2·9	3·3	3·6	4·0	4·5	4·8	3·9	1·9	0·2	1·9	3·2
21	4·2	4·8	5·4	5·2	4·8	4·0	2·1	0·7	0·2	1·2	1·9	2·5	2·5	3·0	3·4	3·6	4·0	4·6	4·8	3·6	1·7	0·4	2·0	3·2
26	4·2	4·9	5·4	5·3	4·9	4·1	2·3	0·7	0·3	1·3	2·0	2·6	2·6	3·0	3·6	3·8	4·1	4·7	4·9	3·6	1·4	0·5	2·0	3·3
31	4·3	5·1	5·5	5·4	5·0	4·3	2·4	0·6	0·5	1·4	2·1	2·7	2·7	3·3	3·8	3·9	4·3	4·8	5·0	3·5	1·2	0·6	2·1	3·3
April. 5	4·5	5·3	5·7	5·7	5·3	4·5	2·7	0·6	0·6	1·6	2·3	2·8	2·8	3·5	4·0	4·1	4·5	5·0	5·2	3·4	1·2	0·7	2·2	3·5
10	4·6	5·5	5·9	6·0	5·6	4·8	3·0	0·7	0·7	1·7	2·5	3·0	3·0	3·7	4·3	4·5	4·9	5·3	5·4	3·4	1·1	0·8	2·3	3·6
15	4·9	5·8	6·2	6·3	5·9	5·2	3·4	0·8	0·7	1·8	2·6	3·1	3·3	4·0	4·7	4·9	5·3	5·7	5·5	3·3	1·0	1·0	2·5	3·9
20	5·1	6·1	6·5	6·6	6·2	5·6	3·7	1·0	0·8	2·0	2·7	3·3	3·5	4·4	5·1	5·3	5·8	6·1	5·7	3·1	0·9	1·1	2·7	4·1
25	5·4	6·4	6·8	6·8	6·5	5·9	4·0	1·3	0·8	2·1	2·9	3·5	3·9	4·8	5·5	5·9	6·4	6·0	5·7	3·0	0·8	1·3	3·0	4·3
30	5·6	6·6	7·0	7·1	6·8	6·2	4·4	1·5	0·8	2·1	3·0	3·7	4·2	5·1	5·9	6·4	6·9	6·8	5·7	2·9	0·7	1·6	3·2	4·6
May. 5	5·7	6·7	7·1	7·2	7·0	6·5	4·6	1·7	0·7	2·2	3·1	3·9	4·6	5·5	6·3	6·9	7·3	6·4	5·7	2·7	0·5	1·8	3·3	4·7
10	5·9	6·8	7·2	7·3	7·1	6·7	4·9	2·0	0·6	2·2	3·1	4·0	4·8	5·7	6·5	7·2	7·6	7·7	5·5	2·5	0·3	2·0	3·7	4·9
15	5·9	6·8	7·2	7·2	7·2	6·8	5·0	2·2	0·5	2·3	3·3	4·2	5·0	5·9	6·7	7·4	7·9	7·8	5·4	2·4	0·2	2·1	3·8	4·9
20	5·9	6·8	7·1	7·2	7·3	6·9	5·4	2·4	0·4	2·3	3·3	4·3	5·1	5·9	6·7	7·5	8·0	7·9	5·2	2·3	0·1	2·0	3·9	5·0
25	5·9	6·7	7·0	7·2	7·3	6·9	5·5	2·5	0·4	2·3	3·4	4·4	5·2	6·0	6·8	7·5	8·0	7·9	5·1	2·3	0·1	2·2	3·9	5·0
30	5·8	6·6	6·9	7·2	7·3	6·8	5·5	2·6	0·3	2·3	3·5	4·4	5·2	5·9	6·7	7·5	8·0	7·8	5·1	2·3	0·1	2·1	3·8	4·9
June. 5	5·8	6·6	6·9	7·2	7·4	6·9	5·6	2·7	0·3	2·3	3·6	4·5	5·2	5·9	6·6	7·5	8·0	7·8	5·1	2·4	0·1	2·0	3·7	4·8
10	5·8	6·6	6·9	7·3	7·5	7·0	5·7	2·9	0·2	2·3	3·6	4·6	5·2	5·9	6·6	7·4	7·9	7·9	5·1	2·4	0·0	1·9	3·6	4·8
15	5·9	6·6	7·0	7·4	7·6	7·0	5·7	3·0	0·3	2·5	3·8	4·8	5·3	6·0	6·7	7·5	8·0	7·9	5·2	2·4	0·1	1·8	3·5	4·8
20	6·0	6·7	7·2	7·6	7·9	7·2	5·9	3·1	0·3	2·5	3·9	4·9	5·5	6·2	6·8	7·7	8·2	8·1	5·3	2·4	0·1	1·8	3·5	4·8
25	6·1	6·9	7·5	7·8	8·0	7·3	6·2	3·3	0·4	2·7	4·0	5·1	5·7	6·4	7·0	7·8	8·4	8·3	5·5	2·3	0·0	1·8	3·5	4·9
30	6·3	7·2	7·8	8·1	8·3	7·7	6·4	3·4	0·4	2·8	4·1	5·2	5·9	6·7	7·3	8·0	8·7	8·6	5·6	2·3	0·0	1·9	3·6	5·0

Table III. (Continued.)

Second Part, July to December. The corrections in the smaller type are subtractive; in the larger type additive.

Days of the month.	Hours of Mean Astronomical Time.																							
	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
	Subtractive.								Additive.												Subtractive.			
July. 5	6·5	7·4	8·1	8·4	8·5	8·0	6·7	3·5	0·5	2·9	4·2	5·3	6·2	6·9	7·6	8·3	8·9	9·0	8·8	8·3	0·1	2·0	3·7	5·2
10	6·7	7·6	8·4	8·6	8·7	8·2	6·8	3·5	0·6	3·0	4·3	5·5	6·4	7·2	7·8	8·5	9·2	9·2	8·0	8·4	0·1	2·2	3·9	5·4
15	6·9	7·8	8·6	8·8	8·8	8·4	6·9	3·5	0·7	3·1	4·3	5·5	6·5	7·4	8·0	8·7	9·3	9·4	8·2	8·5	0·1	2·3	4·0	5·6
20	7·0	7·8	8·7	8·9	8·9	8·4	6·8	3·3	0·9	3·2	4·3	5·5	6·6	7·5	8·0	8·8	9·3	9·4	8·4	8·7	0·1	2·4	4·1	5·7
25	7·0	7·9	8·8	8·9	8·9	8·4	6·7	3·1	1·0	3·2	4·3	5·4	6·6	7·4	8·0	8·7	9·2	9·3	8·4	8·9	0·0	2·4	4·3	5·8
30	7·0	7·9	8·7	8·9	8·8	8·3	6·5	2·8	1·1	3·1	4·2	5·3	6·4	7·2	7·8	8·5	9·0	9·0	8·5	8·1	0·1	2·4	4·3	5·8
August. 5	6·9	7·7	8·5	8·8	8·6	8·1	6·3	2·4	1·2	3·1	4·2	5·1	6·1	6·9	7·5	8·2	8·6	8·7	6·6	3·3	0·2	2·4	4·3	5·8
10	6·6	7·4	8·1	8·4	8·3	7·8	5·9	2·0	1·3	3·1	4·0	5·0	5·9	6·6	7·3	7·9	8·3	8·4	6·7	3·6	0·3	2·2	4·2	5·6
15	6·5	7·3	7·9	8·2	8·1	7·5	5·6	1·7	1·3	2·8	3·9	4·7	5·5	6·1	6·8	7·5	7·8	8·0	6·6	3·6	0·3	2·2	4·1	5·6
20	6·3	7·0	7·6	7·9	7·8	7·2	5·2	1·3	1·3	2·7	3·7	4·4	5·1	5·7	6·4	7·1	7·5	7·8	6·5	3·7	0·4	2·0	4·0	5·4
25	6·2	6·8	7·3	7·6	7·5	7·0	4·7	1·0	1·2	2·5	3·5	4·2	4·8	5·4	6·1	6·7	7·1	7·5	6·5	3·6	0·4	1·9	3·9	5·3
30	6·1	6·7	7·1	7·4	7·2	6·6	4·3	0·7	1·2	2·3	3·4	4·0	4·5	5·1	5·8	6·4	6·8	7·3	6·4	3·6	0·5	1·8	3·8	5·2
September. 5	6·0	6·6	7·0	7·2	7·0	6·3	3·9	0·6	1·0	2·1	3·2	3·9	4·3	4·8	5·5	6·1	6·6	6·7	6·3	3·6	0·6	1·7	3·6	5·1
10	5·9	6·5	6·9	7·0	6·9	6·1	3·4	0·4	1·0	2·0	3·1	3·7	4·1	4·7	5·3	5·8	6·4	7·0	6·2	3·6	0·7	1·6	3·6	5·0
15	5·9	6·5	6·9	7·0	6·7	5·8	3·1	0·4	0·9	1·9	3·0	3·6	4·0	4·6	5·2	5·6	6·2	6·8	6·2	3·6	0·9	1·6	3·5	5·0
20	5·9	6·5	6·9	6·9	6·5	5·5	3·0	0·3	0·8	1·8	2·9	3·5	3·9	4·5	5·0	5·4	6·0	6·7	6·1	3·7	1·0	1·4	3·4	4·9
25	5·9	6·5	6·9	6·7	6·4	5·1	2·6	0·4	0·7	1·7	2·7	3·4	3·8	4·4	4·9	5·3	5·8	6·4	6·0	3·8	1·2	1·4	3·4	4·9
30	5·8	6·4	6·8	6·6	6·2	4·7	2·3	0·3	0·6	1·6	2·6	3·3	3·7	4·3	4·8	5·0	5·5	6·1	5·7	3·9	1·4	1·3	3·3	4·8
October. 5	5·7	6·2	6·6	6·4	5·9	4·3	1·9	0·3	0·6	1·5	2·4	3·2	3·6	4·2	4·6	4·8	5·3	5·7	5·4	4·0	1·5	1·2	3·2	4·7
10	5·6	6·0	6·4	6·2	5·6	3·9	1·7	0·3	0·5	1·4	2·2	2·9	3·4	4·0	4·4	4·6	4·9	5·2	5·0	3·9	1·5	1·2	3·2	4·6
15	5·3	5·7	6·1	5·8	5·1	3·4	1·3	0·2	0·5	1·3	2·0	2·7	3·2	3·8	4·2	4·3	4·6	4·8	4·6	3·8	1·6	1·1	3·0	4·4
20	5·0	5·4	5·7	5·5	4·7	2·9	1·1	0·2	0·5	1·1	1·8	2·4	3·1	3·6	3·9	4·0	4·4	4·4	4·1	3·6	1·5	1·0	2·9	4·1
25	4·7	5·0	5·3	5·1	4·2	2·5	1·0	0·1	0·4	1·0	1·6	2·2	2·9	3·3	3·6	3·7	4·0	4·0	3·6	3·3	1·4	0·9	2·6	3·9
30	4·3	4·6	4·8	4·6	3·7	2·1	0·8	0·1	0·4	0·9	1·4	1·9	2·7	3·0	3·3	3·5	3·7	3·6	3·2	3·1	1·4	0·7	2·4	3·5
November. 5	3·9	4·3	4·4	4·2	3·3	1·9	0·8	0·1	0·3	0·7	1·2	1·6	2·4	2·7	2·9	3·2	3·4	3·3	2·9	2·8	1·3	0·6	2·1	3·2
10	3·6	3·9	4·1	3·9	3·0	1·6	0·7	0·1	0·3	0·6	1·0	1·4	2·1	2·4	2·7	3·0	3·1	3·0	2·6	2·6	1·4	0·3	1·8	2·8
15	3·3	3·7	3·8	3·6	2·7	1·5	0·7	0·1	0·2	0·5	0·8	1·2	1·8	2·1	2·4	2·7	2·9	2·8	2·5	2·5	1·4	0·1	1·5	2·5
20	3·1	3·5	3·6	3·4	2·6	1·5	0·5	0·2	0·1	0·4	0·7	1·0	1·6	1·9	2·2	2·5	2·6	2·4	2·5	2·5	1·6	0·2	1·2	2·3
25	2·9	3·4	3·5	3·3	2·5	1·4	0·5	0·2	0·1	0·3	0·6	0·8	1·3	1·6	2·0	2·3	2·5	2·4	2·5	2·5	1·8	0·5	1·0	2·0
30	2·8	3·4	3·5	3·2	2·5	1·5	0·6	0·3	0·0	0·2	0·5	0·7	1·1	1·5	1·9	2·2	2·3	2·2	2·5	2·6	2·0	0·7	0·8	1·9
December. 5	2·7	3·3	3·4	3·2	2·5	1·5	0·7	0·4	0·0	0·2	0·5	0·6	1·0	1·4	1·8	2·1	2·1	2·1	2·5	2·7	2·1	0·9	0·6	1·8
10	2·5	3·2	3·4	3·1	2·4	1·5	0·7	0·4	0·0	0·2	0·5	0·6	0·9	1·5	1·9	2·1	2·1	1·9	2·5	2·7	2·2	1·0	0·5	1·8
15	2·5	3·2	3·4	3·1	2·5	1·5	0·8	0·5	0·1	0·2	0·5	0·6	0·9	1·5	1·9	2·0	2·0	2·0	2·5	2·6	2·2	1·0	0·4	1·7
20	2·4	3·1	3·3	3·0	2·4	1·5	0·8	0·5	0·1	0·1	0·4	0·6	1·0	1·6	1·9	2·1	2·0	2·0	2·3	2·5	2·1	1·0	0·4	1·6
25	2·4	3·0	3·2	3·0	2·4	1·6	0·8	0·4	0·1	0·1	0·4	0·6	1·1	1·7	1·9	2·0	2·0	2·1	2·2	2·2	1·9	0·9	0·4	1·6
30	2·3	2·9	3·1	3·0	2·2	1·5	0·8	0·4	0·1	0·1	0·5	0·7	1·2	1·8	2·0	2·0	2·1	2·1	1·9	2·0	1·8	0·8	0·5	1·6

The temperatures at the several hours of the day and on the several days of the year, computed in the manner which has been described, furnish data for the delineation of the Chrono-Isothermal Lines in Plate X. figs. 1 and 2. The representation in this Plate of the phenomena of the temperature at Toronto is on the same principle which has long been used in maps of the magnetic isogonic, isoclinal, and isodynamic lines, in which three variables are comprehended, of which one, the magnetical element, is dependent upon the other two, viz. the geographical latitude and longitude. The principle is also the same as that adopted in ordinary isothermal maps; but, whereas in those maps the two variables upon which the meteorological variation is dependent are the geographical latitude and longitude, in the present case the two variables are the hour of the day and the day of the year. The variation of the temperature is here referred to *time* and not to *space*. This difference is intended to be conveyed by the term Chrono-Isothermals as applicable to lines of the present description, whilst those of the more customary form might not inappropriately be termed, for contradistinction, as suggested to me by Mr. Wheatstone, Topo-Isothermals. Representations of the Chrono-Isothermals in different localities might materially facilitate the comparison of the phenomena of the temperature in different parts of the globe; and if similar plates were constructed for each of the meteorological elements at the same locality, they might be useful for intercomparison, and for illustrating the mutual dependence of the elements on each other, to those who prefer a representation to the eye to the instruction conveyed by tabular abstracts. In fig. 1 the isothermals are represented which are comprised between the mean temperature of the year and the *highest* isothermal; in fig. 2 between the mean temperature and the *lowest* isothermal. In fig. 1, consequently, the isothermals increase in value from the circumference to the centre; whilst in fig. 2 they decrease from the circumference to the centre. To avoid too great a multiplicity of lines only every alternate degree (the even degrees of Fahrenheit's scale) are drawn. Figs. 1 and 2 are so arranged on the Plate that the summer and winter solstices (marked by a dotted line) are in the same vertical. The abnormal character of the winter temperature of the North American Continent is strikingly manifested in this Plate.

From the temperatures computed from the six years of observation and represented in the plate, we learn many facts regarding the temperature at Toronto, which are interesting in themselves, and may become particularly so in their comparison with the phenomena in other parts of the globe. Amongst these may be noticed the following:—The mean annual range, or the difference between the mean temperatures of the coldest and hottest months (February and July), is 42°.7. The warmest day of the year is July 28, being thirty-seven days after the summer solstice. The coldest day is February 14, being fifty-five days after the winter solstice. The mean temperature of the year is passed through on April 19 and October 15. The warmest and coldest days, and the days on which the mean temperature is passed through,

deduced by a similar process at Königsberg by Bessel, at Paris, Turin and Padua by Kämtz, at Berlin by Mädler, and at Prague by Fritsch and Jelinek, are collected by the last-named meteorologist in his memoir "On the daily march of the principal meteorological elements deduced from hourly observations at the Prague Observatory," published in the Transactions of the Imperial Academy of Sciences at Vienna in 1850, and are as follows:—

	Maximum.	Minimum.	Days on which the mean temp. of the year is passed through.	
Königsberg	August 1	January 9	April 21	October 20
Berlin (18 years) . .	July 18	January 19	April 19	October 21
Berlin (92 years) . .	July 22	January 12	April 17	October 16
Prague (8 to 9 years) .	July 24	January 26	April 16	October 20
Prague (76 years) . .	July 23	January 19	April 15	October 18
Paris	July 28	January 15	April 18	October 19
Turin	July 27	January 3	April 18	October 26
Padua	July 26	January 15	April 20	October 15

These may be compared with the corresponding epochs at Toronto, as derived respectively from the six-years and the twelve-years series discussed in this paper:

Toronto (1842, 5 to 1848, 5)	July 28	February 14	April 19	October 15
Toronto (1841 to 1852)	July 28	February 12	April 25	October 17

The anomalous character of the North American winter, so visible in the Chrono-Isothermal Plate, is also marked by the very late occurrence of the epoch of the *minimum* temperature, and the great dissimilarity in that respect from all the other stations. The systematic character of this anomaly is further shown by the fact, that every hour in the twenty-four has its minimum temperature between the 7th and 17th of February; the minimum occurs earliest, viz. on the 7th of February, at the hour of 2 P.M.; the minima of the hours of the night, or from 9 P.M. to 7 A.M. inclusive, fall the latest, viz. on the 15th, 16th and 17th of February; those of the intermediate hours on the intermediate days and in regular progression. The hours from 6 A.M. to 9 P.M. inclusive, or those of the *day*, have their *maximum* temperature between the 20th and 30th of July; those of the *night*, or from 11 P.M. to 5 A.M. inclusive, from the 3rd to the 12th of August. The portion of the twenty-four hours which is warmer than the mean temperature of the day varies considerably at different seasons; in part of November there are fourteen of the observation hours colder, and only ten warmer than the mean temperature of the day; in the greater part of July twelve of the observation hours are colder and twelve warmer; and in all the rest of the year thirteen hours colder and eleven warmer. This is seen in detail in Table III.; the dark lines which separate the additive from the subtractive corrections pass between the hours which are above and those which are below the mean temperature on every fifth day of the year. On the average of the whole year the mean tempe-

rature is passed through about $8^h\ 31^m$ A.M., and $7^h\ 44^m$ P.M., making intervals of $11^h\ 13^m$ and $12^h\ 47^m$. The hours from 9 P.M. to 7 A.M. inclusive are throughout the year colder than the mean temperature of the day; those from 10 A.M. to 7 P.M. are throughout the year warmer than the mean temperature of the day; 8 and 9 A.M., and 8 P.M., are sometimes warmer and sometimes colder than the mean temperature; 8 A.M. is colder except for about three weeks in July, and 9 A.M. is warmer except from November 20 to March 11; 8 P.M. is colder from the middle of March till late in November, and either coincides with the mean temperature, or is slightly warmer during the remainder of the year.

The hours of highest and lowest temperature on every fifth day of the year, and the amount by which the temperature at those hours exceeds or falls short of the mean temperature of the day, may be examined in detail in Table III. From the third week of September until April, 2 P.M. is the warmest hour, with the exception of some days in January and February, when 3 P.M. is warmer; from April to the middle of May, and again from the end of July to the middle of September, 3 P.M. is the warmest hour; and from the middle of May to the middle of July, 4 P.M. The coldest hour from the latter part of April to the end of June, and again from the end of October to late in November, is 4 A.M.; from the middle of July to the middle of October, in January, and for a short time in the middle of April, it is 5 A.M.; from the latter end of February to early in April it is 6 A.M.; and generally in December and February 7 A.M. The range from the minimum to the maximum in the day is greatest in July (18°·2), and least at the end of December (5°·2). The daily range has but one maximum in the year, which is in July; not as at Prague, where June and July have a less range than the months immediately preceding and following them, and where consequently there are two maxima; a phenomenon attributed to the greater prevalence of clouds in June and July.

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It may be desirable to add a few words on the assistance to observers of tables which furnish corrections to the mean temperature of the day for every hour of every day in the year, such as Table III. Besides their direct use at the station itself, they have a useful bearing, within a reasonable distance from the station, on the selection of observation hours in the many cases in which it may not be possible to observe at hourly or two-hourly intervals, by affording a ready means of estimating the amount of error to which a deduction from any limited combination of hours is subject. If we desire for example to seek the observation hours within the command of a single observer, which may give the best approximation to the mean temperature of the day, and to that of the month, and of the year, as well as to the *climatic* difference (*i. e.* the difference between the hottest and the coldest months), we find, that of homonymous hours, the best pairs at Toronto are 9^h—9^h and 10^h—10^h, 10^h—10^h being the better of the two; but that 8^h—8^h, which is a combination frequently adopted by observers, does not suit so well at Toronto as either 9^h—9^h or 10^h—10^h. The average errors in the different months, when the temperature is inferred from

observations at 9^h—9^h or 10^h—10^h instead of from hourly observations, are shown on the average of six years to be as follows:—the sign + denoting that the mean daily temperature in the month is given too high, and − that it is given too low, by the mean of the two compared with the mean of the twenty-four observations.

	9^h—9^h			10^h—10^h		
January	−0°·4	July	−0°·4	January	0°·0	July	−0°·2
February	−0·8	August	−0·3	February	−0·1	August	+0·1
March	−0·5	September	−0·2	March	+0·1	September	+0·3
April	−0·4	October	−0·1	April	−0·1	October	+0·5
May	−0·1	November	−0·2	May	+0·3	November	+0·4
June	−0·3	December	−0·6	June	−0·2	December	0·0
Mean of the year			−0°·36	Mean of the year			+0°·09

Difference of the hottest and coldest months:

Too great by 0°·4 — Too great by 0°·15

For the purpose of combining with an approximate mean temperature of the day, an approximation also to the hottest and coldest hours of the day, and to the hours of maximum and minimum of other meteorological elements, *three* equidistant observations are frequently adopted in preference to a binary system, and the hours of 6 A.M., 2 P.M. and 10 P.M. appear to be usually preferred. These hours are still within the command of a single observer, though we often find substituted for them the non-equidistant hours of 7 A.M., 2 P.M. and 9 P.M., doubtless because they suit better the convenience of observers. On comparing the mean temperatures in the different months derived from 6^h, 2^h, 10^h, or 7^h, 2^h, 9^h, with the full complement of twenty-four hours, we find that the approximation to the mean temperature obtained by 7^h, 2^h, 9^h is not quite so good as by 6^h, 2^h, 10^h; and that either of the triplets give a less correct mean temperature than 10^h—10^h: $6\frac{1}{2}$, 2, $9\frac{1}{2}$ would appear a more suitable combination as far as regards approximation to the mean temperature.

	6 A.M., 2 P.M., 10 P.M.			7 A.M., 2 P.M., 9 P.M.			
January	+0°·3	July	−0°·6	January	+0°·4	July	+1°·0
February	−0·1	August	−0·9	February	0·0	August	+0·5
March	−0·4	September	−0·7	March	+0·1	September	+0·5
April	−0·6	October	−0·2	April	+0·4	October	+0·3
May	−0·5	November	+0·2	May	+0·8	November	+0·3
June	−0·7	December	+0·1	June	+0·7	December	+0·2
Mean of the year			−0°·34	Mean of the year			+0°·43

Difference of the hottest and the coldest months:

Too small by 0°·4 — Too great by 1°·0

Three equidistant observations in the twenty-four hours are the utmost that can

be perseveringly maintained by a single observer. When there are two or more observers, there is no difficulty in multiplying the times of observation so as to comprehend all the objects that may be desired, each in the manner and by the means which are most suitable to it and will be most satisfactory. But as the work of observation at by far the greater number of meteorological stations is usually carried out by a single observer, and as this is likely to be always the case, it should be a primary object with meteorologists who are furnished with sufficient means, to form tables of corrections to the mean daily temperature for every hour of the day, upon the basis of a sufficient number of years of observation, to be used at the respective localities, or within the distances to which such tables may be severally applicable, by persons whose means or convenience may restrict them in respect to the number and choice of hours of observation. With such a table, similar to Table III. of this paper, the choice is disembarrassed of its chief difficulty, that of selecting hours which by their combination will give an approximate mean temperature for the several months and for the year; and the observer is left free to give a preference, independent of such consideration, either to the hours when the phenomena change least rapidly, and when consequently small irregularities in the times of observation will be least injurious, or to the hours which will furnish the best approximation to the daily maxima and minima of the meteorological elements generally, viz. of the temperature, the tension of vapour, the pressure of the gaseous atmosphere, and the force of the wind; or to the hours which will have the most effective bearing upon other points of meteorological or climatic interest, to which the observer's attention may be directed.

The equation of the mean annual variation of the temperature, in the form most convenient for use, deduced from the twelve monthly means in the lowest horizontal line of Table I., is as follows:—

$$\begin{aligned} t_x = {} & +44^\circ{\cdot}32 - 21^\circ{\cdot}57 \sin(a+82^\circ\ 58') + 0^\circ{\cdot}81 \sin(2a+278^\circ\ 32') \\ & - 1^\circ{\cdot}43 \sin(3a+333^\circ\ 48') + 0^\circ{\cdot}44 \sin(4a+30^\circ\ 04') \\ & + 0^\circ{\cdot}73 \sin(5a+37^\circ\ 48') + 0^\circ{\cdot}32 \cos 6a, \end{aligned}$$

in which $a = n \times 30^\circ$, n denoting the number of months and parts of a month between January 15th and x.

The equation of the mean diurnal variation of the temperature deduced from the twenty-four hourly means in the last vertical column of Table I. is—

$$\begin{aligned} t_x = {} & +44^\circ{\cdot}32 + 5^\circ{\cdot}513 \sin(a+53^\circ\ 40') + 0^\circ{\cdot}82 \sin(2a+59^\circ\ 08') \\ & - 0^\circ{\cdot}48 \sin(3a+41^\circ\ 41') - 0^\circ{\cdot}06 \sin(4a+51^\circ\ 23') \\ & + 0^\circ{\cdot}04 \sin(5a+20^\circ\ 35'), \end{aligned}$$

in which $a = n \times 15^\circ$, n being the number of hours and parts of an hour between x, and 0 hours or astronomical mean noon.

I now proceed to the second portion of the series, or to the six years in which the

observations were for the most part made on a less perfect system than that of twelve or twenty-four equidistant observations in the twenty-four hours. The hours of observation during this portion of the series were as follows:—

January 1841 to June 1842 inclusive; two-hourly equidistant.
July 1848 to December 1848 inclusive; 2, 3, 4, 9, 10, 11, 17, 19, 21, 22.
1849. January to December inclusive; 1, 2, 3, 5, 6, 9, 10, 11, 18, 19, 20, 22.
1850. January to April inclusive; hourly.
1850. May to June inclusive; 2, 3, 10, 11, 18, 19.
1850. July and August; hourly.
1850. September to December inclusive; two-hourly equidistant.
1851. January to April inclusive; two-hourly equidistant.
1851. May to December inclusive; 2, 4, 10, 12, 18, 20.
1852. January to December inclusive; 2, 4, 10, 12, 18, 20.

Whenever the observations during these six years were either hourly, or two-hourly and equidistant, a mean of the observations simply, without corrections applied to any of them, has been taken as the mean temperature of the day. In all the other cases corrections taken from Table III. have been applied individually to the observations at the hours to which they refer, and the mean temperature of the day has been computed from the mean of the observations so corrected.

Having thus obtained the mean daily temperatures during the second period of six years, we have the mean monthly temperatures derived from the twelve years as follows:—

January .	24°·97	April .	41°·14	July . .	66°·41	October .	44°·93
February .	23·40	May .	51·18	August . .	66·16	November .	36·51
March . .	30·23	June .	61·05	September	58·02	December .	26·75

Mean of the whole 44°·23.

Employing these values, we obtain the formula representing the mean annual variation of the temperature at Toronto as follows:—

$$t_a = +44°{\cdot}23 - 21°{\cdot}81 \sin(a + 81°\ 27') + 1°{\cdot}06 \sin(2a + 71°\ 32') - 0°{\cdot}80 \sin(3a + 347°\ 42') + 0°{\cdot}22 \sin(4a + 37°\ 27') + 0°{\cdot}88 \sin(5a + 50°\ 41') + 0°{\cdot}325 \cos 6a,$$

$a = n \times 30°$; n being reckoned as before from January 15th.

Table IV. (pages 154 to 159 inclusive) exhibits in column 1 the mean temperature of every day of the year, computed by the preceding formula; and in columns 2 to 13, under the respective years 1841 to 1852, the differences of the mean temperatures actually observed on each day from the mean of the twelve years computed as described and shown in column 1. These "differences" are the *non-periodic variations* of each day, on the assumption that the monthly means of twelve years furnish a sufficient basis for the deduction of approximate normal values; which is certainly

true within the limits which are at present required for the comparison of the non-periodic variations in Europe and America. The observed temperatures themselves may be obtained, if they are required, by adding or subtracting (as the case may be) from the mean daily temperature in column 1, the difference which stands on the same horizontal line with the *day*, and in the same vertical line with the *year*. The final column (14) shows for each day the *average* non-periodic variation in twelve years. We may learn, consequently, from this column, the average non-periodic variation in twelve years of any particular day of the year which may be surmised to be subject to some special physical peculiarity, causing it to be warmer or colder than the general progression of the temperature in the part of the year to which it belongs. An example of its application may be given by the reply which the values in this column furnish to the question*, whether the three days of May (the 11th, 12th, and 13th), which MÄDLER has stated to be characterized, on the average of eighty-six years of observation at Berlin, by a depression exceeding 2° FAHR. when compared with the general march of the temperature at that season, undergo a similar depression in North America. On a reference to the month of May in Table IV., it is seen in column 14 that on the average of the twelve years from 1841 to 1852, the 11th of May was 0°·1 *below*, and on the 12th and 13th of May respectively 3°·1 and 2°·4 *above* the general mean of the temperature in those years. It may be seen also that the average non-periodic variation in the five days from the 8th to the 12th of May inclusive, is in the same twelve years 1°·1 *above*, and in the five days from the 13th to the 17th inclusive 1°·0 *above*, the general mean of the temperature. The meteorological observations at Toronto during these twelve years do not therefore support the supposition that the depression of temperature on the 11th, 12th and 13th of May, observed at Berlin, is a general and periodically recurring phenomenon over the whole globe; such as would be occasioned by a partial obscuration of the sun's disc by the intervention of a periodical stream of aërolites; but they tend rather to indicate that the depression observed in Europe may have been a partial phenomenon, having a local cause.

The not unfrequent occurrence of differences of large amount on single days, shown in columns 2 to 13, is an indication of the great variability of the climate of Toronto in regard to temperature; and the still remaining occasional magnitude of the daily averages in column 14, shows that the influence of non-periodic variations is by no means extinguished in the means of twelve years.

* Kosmos, Bd. i. S. 407. Anm. 56.

TABLE IV.—Non-Periodic Variations of the Temperature at Toronto, from January 1841 to December 1852 inclusive.

		Daily temperature derived from the monthly mean of the 12 years.	Difference on each day of the twelve years from the temperature derived from the monthly means.												Mean daily difference.
			1841.	1842.	1843.	1844.	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	
		(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)	(9.)	(10.)	(11.)	(12.)	(13.)	(14.)
January.	1	25°2	− 9°6	+ 8°2	Sunday.	− 0°1	+ 9°9	+ 8°5	+ 9°8	+19°0	−11°2	− 3°7	− 2°0	+ 0°4	+5°7
	2	25·2	− 9·6	Sunday.	− 1·3	+ 8·1	+ 5·4	+ 9·0	+10·2	Sunday.	−26·0	− 5·1	− 3·8	− 2·3	−0·5
	3	25·1	Sunday.	− 9·6	−14·7	+ 7·4	+12·4	+ 7·8	Sunday.	+11·5	−17·0	− 2·7	− 9·5	− 2·1	−1·7
	4	25·1	−18·4	− 3·7	− 7·2	− 2·6	+10·2	Sunday.	+11·7	− 1·1	− 6·4	− 3·9	−11·0	Sunday.	−3·2
	5	25·1	− 4·8	−11·5	+ 3·3	− 4·8	Sunday.	+ 4·8	+10·2	− 0·1	− 4·1	− 4·2	Sunday.	− 1·4	−1·3
	6	25·1	+11·5	+ 7·6	+11·8	+ 1·6	− 7·1	+ 8·1	+ 6·4	−13·4	− 6·5	Sunday.	+ 2·5	− 4·7	+1·6
	7	25·1	+10·6	+ 0·2	+13·4	Sunday.	− 1·4	+10·3	− 4·6	− 3·3	Sunday.	+ 4·5	− 3·1	−15·8	+1·1
	8	25·1	− 3·4	+ 2·5	Sunday.	−10·0	+ 4·4	+ 6·9	−15·4	+ 4·6	− 1·7	+ 3·1	+ 1·4	− 3·3	−1·0
	9	25·1	− 2·2	Sunday.	+ 2·9	− 1·7	+ 7·2	+ 3·9	− 9·4	Sunday.	−15·4	+ 8·0	+11·8	+ 2·2	+0·7
	10	25·1	Sunday.	− 0·9	+ 7·8	− 4·4	+ 3·6	+ 4·7	Sunday.	−21·3	−27·8	+ 0·7	+ 9·1	− 3·8	−3·2
	11	25·0	+ 5·3	+ 5·7	+ 5·6	− 5·9	+ 1·0	Sunday.	−14·4	− 6·1	−26·6	+12·0	+ 7·1	Sunday.	−1·6
	12	25·0	+ 4·4	− 1·7	+ 7·4	+10·3	Sunday.	− 4·0	− 8·1	− 1·1	− 7·3	+ 5·1	Sunday.	−10·0	−0·5
	13	25·0	+ 0·1	− 6·6	+ 2·0	+ 5·5	− 8·2	− 3·8	+ 7·6	+11·3	+10·1	Sunday.	+ 5·7	−14·7	+0·8
	14	25·0	+ 3·7	+ 9·7	− 1·3	Sunday.	− 7·5	+ 3·1	+11·8	+13·7	Sunday.	− 7·3	+12·3	− 1·0	+3·7
	15	25·0	+ 6·5	0·0	Sunday.	+ 7·6	+ 4·7	+10·3	+15·0	+15·3	+ 2·8	+ 6·0	+10·9	−21·5	+5·2
	16	24·9	+11·2	Sunday.	− 1·6	+12·5	− 0·7	− 0·7	− 1·0	Sunday.	− 5·8	+ 9·7	+11·8	− 8·5	+2·7
	17	24·9	Sunday.	+ 9·1	+ 1·4	+ 2·9	− 5·3	−16·4	Sunday.	+ 2·3	− 4·8	+10·2	− 7·2	−18·4	−2·6
	18	24·9	−22·5	+10·1	+11·1	− 0·8	−10·2	Sunday.	+ 3·7	− 8·0	−14·2	+ 4·9	−15·2	Sunday.	−4·1
	19	24·8	−15·4	+12·8	+14·6	− 9·4	Sunday.	−14·7	−16·2	− 4·9	−10·7	+ 2·3	Sunday.	−23·6	−6·5
	20	24·8	− 0·1	+10·4	+13·3	−14·7	+ 2·1	− 5·2	− 9·1	+12·1	− 0·4	Sunday.	+ 7·2	−24·3	−0·8
	21	24·7	+ 4·7	+ 1·3	+18·8	Sunday.	+ 6·3	− 7·3	−16·8	+ 6·6	Sunday.	+11·1	+ 5·8	−14·5	+1·6
	22	24·7	+ 0·8	−12·3	Sunday.	− 1·9	+ 1·5	−13·6	− 9·9	− 2·4	− 5·5	+ 5·2	+10·3	−17·0	−4·1
	23	24·6	+ 4·6	Sunday.	+ 9·1	+12·7	+ 8·2	− 9·0	+ 2·5	Sunday.	+ 0·4	+ 6·5	+ 8·3	− 7·1	+3·6
	24	24·5	Sunday.	− 3·2	+ 7·4	−10·5	+10·7	+ 4·1	Sunday.	+ 3·0	+ 7·7	+11·6	+ 8·8	+ 1·4	+4·1
	25	24·5	+ 4·8	+ 9·1	−10·1	−25·8	− 0·4	Sunday.	+ 0·5	+11·6	+11·5	+12·4	+ 6·6	Sunday.	+2·0
	26	24·4	+ 5·8	+ 5·6	− 7·8	−25·5	Sunday.	+ 8·1	+ 1·1	+14·1	+ 3·3	+ 9·0	Sunday.	− 6·4	+0·7
	27	24·3	+10·5	− 3·0	+ 3·1	−24·7	+ 9·1	− 0·3	−14·5	+13·0	− 2·4	Sunday.	− 3·7	− 1·3	−0·4
	28	24·3	+ 4·0	+12·0	− 0·3	Sunday.	+11·4	+ 9·8	− 7·5	+ 7·1	Sunday.	+ 2·8	+ 8·9	+ 8·7	+5·7
	29	24·2	+ 8·4	+16·2	Sunday.	−20·9	+ 0·5	+11·7	+ 2·3	+ 5·6	+ 9·6	+ 0·6	−22·5	+10·4	+2·0
	30	24·1	+ 4·5	Sunday.	+ 6·0	−15·4	− 8·3	+12·3	− 9·0	Sunday.	−10·2	+ 2·4	−25·6	+ 1·0	−4·2
	31	24·0	Sunday.	+ 8·2	+ 6·4	−18·9	−18·1	− 9·1	Sunday.	+ 8·2	−14·7	+ 9·2	−10·3	− 0·2	−3·9
February.	1	23·9	−10·0	+ 7·1	−13·5	− 5·3	−20·6	Sunday.	+ 6·3	+ 0·9	+ 4·4	+ 3·5	− 1·9	Sunday.	−2·9
	2	23·9	− 0·7	+14·5	− 9·3	− 2·3	Sunday.	+ 4·7	+14·2	+ 8·9	+ 6·2	+ 5·6	Sunday.	+ 0·2	+4·2
	3	23·8	− 6·6	+18·3	− 0·8	− 5·3	− 3·2	+11·7	+ 2·3	+ 8·9	− 4·5	Sunday.	+ 5·5	+ 5·6	+2·9
	4	23·7	− 0·8	+10·7	+ 1·1	Sunday.	− 7·3	+11·3	− 7·9	+10·9	Sunday.	−16·3	+ 8·1	+13·6	+2·3
	5	23·6	+ 4·3	+ 7·6	Sunday.	+ 9·7	−11·3	+10·3	− 7·3	+ 2·3	− 8·7	−14·1	+ 1·6	+ 9·3	+0·3
	6	23·6	+ 5·8	Sunday.	−14·9	+ 5·8	−12·4	+ 8·8	− 3·7	Sunday.	+ 2·2	− 2·1	−12·9	+ 8·1	−1·5
	7	23·5	Sunday.	+ 6·3	−12·1	− 1·4	− 6·1	+ 7·9	Sunday.	− 1·9	−12·8	+ 8·3	−10·9	+ 5·6	−1·7
	8	23·5	+ 2·8	−14·9	−12·7	− 1·2	−11·7	Sunday.	+ 9·1	+ 0·1	+ 1·2	+12·9	−18·7	Sunday.	−3·3
	9	23·4	+ 4·3	− 0·5	− 9·7	−12·6	Sunday.	−13·3	+ 5·5	+ 6·8	− 7·9	+11·9	Sunday.	+10·0	−0·5
	10	23·4	−10·4	+ 7·4	+ 4·8	− 2·3	+ 6·2	−13·6	+ 1·2	−11·4	− 1·4	Sunday.	+ 3·2	+11·5	−0·4
	11	23·4	−18·9	+12·4	− 4·2	Sunday.	+ 7·4	− 8·6	− 6·0	−13·0	Sunday.	+ 5·7	− 8·7	+10·8	−2·3
	12	23·4	−17·1	+ 5·7	Sunday.	+ 5·0	− 7·6	− 7·6	− 6·0	− 5·5	−17·5	+ 3·7	+ 1·2	− 3·8	−4·5
	13	23·4	− 9·2	Sunday.	− 9·0	+ 9·4	−16·7	+ 3·7	− 2·5	Sunday.	−10·2	+ 4·2	+ 9·6	− 5·1	−2·6
	14	23·4	Sunday.	− 8·0	−15·5	− 1·6	+ 3·4	+ 4·5	Sunday.	+ 6·5	−19·1	+ 4·2	+14·4	− 8·6	−2·0
	15	23·4	− 5·4	+ 0·1	−13·7	+ 6·6	+12·8	Sunday.	− 1·8	+ 1·7	−21·5	− 9·3	+15·0	Sunday.	−1·5
	16	23·5	+ 4·7	− 4·0	−20·0	+ 6·2	Sunday.	− 0·8	− 4·8	+ 5·0	−20·6	+ 1·6	Sunday.	− 6·4	−3·9
	17	23·5	+ 0·5	−11·3	−20·0	− 7·8	+11·4	− 1·3	+ 0·5	+ 4·7	−16·5	Sunday.	+ 6·3	−11·4	−4·1
	18	23·6	+ 4·0	+ 7·1	−18·4	Sunday.	+ 9·0	− 8·1	+ 5·5	+ 7·8	Sunday.	+ 8·8	+ 4·0	−21·0	−0·1
	19	23·7	− 1·1	− 5·6	Sunday.	+ 9·7	+11·4	+ 0·4	+ 6·1	+12·1	−19·8	− 8·0	+10·4	−17·4	−0·2
	20	23·8	+ 7·2	Sunday.	− 9·4	+14·4	+14·9	+ 2·5	− 2·3	Sunday.	− 6·2	+ 9·8	+14·5	−13·7	+3·2
	21	23·9	Sunday.	+ 0·1	− 3·2	+11·5	+15·4	+ 1·9	Sunday.	+14·8	+ 3·7	+ 3·9	+11·3	+ 1·6	+6·1
	22	24·0	+13·6	− 0·9	−11·8	+11·8	+13·7	Sunday.	− 9·9	+10·5	+ 6·5	−12·0	+12·6	Sunday.	+3·4
	23	24·1	−11·4	+ 4·6	−14·8	+ 1·5	Sunday.	− 5·6	−17·5	+ 5·8	+ 8·2	− 3·5	Sunday.	+ 7·2	−2·5
	24	24·3	− 3·4	+ 5·8	− 3·3	− 9·4	+13·7	−12·8	− 6·7	− 1·2	+ 9·3	Sunday.	+11·1	+ 9·7	+1·2
	25	24·5	+ 5·9	+ 1·7	+ 3·6	Sunday.	+18·0	−17·4	− 7·5	− 7·4	Sunday.	+10·8	+ 6·0	+ 3·4	+1·7
	26	24·7	+ 7·4	+ 9·1	Sunday.	+ 9·4	+ 9·1	−25·4	+ 0·2	+ 2·5	+10·0	+13·9	+11·0	− 7·2	+3·6
	27	24·9	+ 9·6	Sunday.	− 2·5	+ 4·9	+ 5·9	−16·4	+ 4·2	Sunday.	+ 9·8	+ 7·4	+ 9·2	− 5·8	+2·6
	28	25·1	Sunday.	+10·0	− 4·7	+ 6·6	+ 5·1	− 9·8	Sunday.	+ 5·4	+11·7	+ 9·4	− 3·0	+ 2·5	+3·3

Table IV. (Continued.)

		Daily temperature derived from the monthly mean of the 12 years.	Difference on each day of the twelve years from the temperature derived from the monthly means.											Mean daily difference.
			1841.	1842.	1843.	1844.	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	
		(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)	(9.)	(10.)	(11.)	(12.)	(13.)	(14.)
March.	1	25°4	+ 2°7	+11°3	−10°7	+15°3	+11°3	Sunday.	− 0°7	−13°2	+ 0°8	+ 5°9	+ 2°1	− 8°1	+1°5
	2	25·6	− 7·4	+15·1	−14·4	+ 9·2	Sunday.	− 8·4	− 1·7	− 9·0	− 2·5	+ 4·1	Sunday.	−12·7	−2·8
	3	25·9	− 2·4	+17·5	−10·8	Sunday.	+ 4·0	− 3·8	+ 1·1	− 5·2	− 5·2	Sunday.	− 4·0	−13·0	−2·2
	4	26·2	− 8·9	+12·7	−11·2	− 8·7	+ 9·6	+ 8·1	− 2·3	− 7·3	Sunday.	− 3·0	+ 4·9	− 5·3	−1·0
	5	26·4	− 6·6	+ 3·9	Sunday.	+ 3·7	+ 9·2	+ 8·5	− 1·0	Sunday.	+ 5·3	+ 6·3	+ 3·1	+ 1·0	+3·3
	6	26·7	− 2·5	Sunday.	−14·1	+ 5·9	+ 7·1	− 5·2	+ 5·6	− 3·0	+ 7·7	+ 7·7	− 0·6	− 7·3	+0·1
	7	27·0	Sunday.	+ 3·3	−13·1	+ 8·2	+11·8	− 1·4	Sunday.	+ 9·3	+10·0	+ 6·1	− 2·6	Sunday.	+3·5
	8	27·4	− 0·5	+ 7·3	− 2·8	+10·8	+18·5	Sunday.	− 1·5	+ 9·6	+ 2·8	− 1·3	− 3·5	+ 5·0	+4·0
	9	27·7	− 0·3	+13·0	− 3·6	+ 3·1	Sunday.	+ 5·2	− 5·5	− 2·8	+ 3·3	+ 2·7	Sunday.	+10·0	+2·5
	10	28·0	− 8·9	+ 8·3	+ 4·4	Sunday.	+ 4·5	+ 4·9	+ 0·4	− 5·8	+ 2·8	Sunday.	+ 3·8	+ 1·0	+1·5
	11	28·4	− 9·7	− 3·6	− 2·0	+10·4	+ 4·6	+ 6·5	−13·1	− 0·4	Sunday.	− 3·2	+ 6·7	+ 4·8	+0·1
	12	28·7	− 1·7	− 4·1	Sunday.	+11·4	+ 7·3	+11·1	−12·8	Sunday.	+ 2·4	+ 0·1	− 4·8	+10·2	+1·9
	13	29·1	− 1·5	Sunday.	− 3·3	+ 9·2	+ 7·7	+10·1	−10·4	− 9·2	+ 7·3	+ 7·7	+ 3·0	+11·0	+2·9
	14	29·5	Sunday.	+ 2·3	− 5·4	+ 1·2	+ 1·3	+ 5·2	Sunday.	−20·2	+ 3·5	+ 9·3	− 0·6	Sunday.	−0·4
	15	29·9	−15·3	+ 4·1	− 9·6	+ 3·6	−11·7	Sunday.	−12·8	−18·8	+ 8·3	+ 3·7	+10·0	+ 4·1	−3·1
	16	30·2	−13·5	+ 9·3	− 9·3	+ 3·4	Sunday.	− 2·0	−13·0	− 5·8	+ 7·4	+ 1·8	Sunday.	+ 2·4	−1·9
	17	30·6	−15·0	+14·7	− 5·8	Sunday.	− 1·5	− 3·1	− 1·4	− 7·8	+ 0·1	Sunday.	+ 3·1	+ 7·5	−0·9
	18	31·0	− 3·2	+ 5·7	− 8·3	−15·3	− 7·5	+ 3·3	+ 2·5	− 1·7	Sunday.	+ 0·4	+ 2·3	− 6·6	−2·6
	19	31·4	+ 7·6	+16·9	Sunday.	− 4·6	− 9·5	+ 6·2	+ 0·6	Sunday.	+ 1·2	− 7·6	− 2·8	−10·4	−0·2
	20	31·8	+13·4	Sunday.	− 9·3	− 5·6	− 3·2	+ 7·4	+ 3·6	+ 3·9	+ 7·6	−13·1	+ 1·9	−15·1	−0·8
	21	32·2	Sunday.	− 1·6	− 9·3	− 8·2	Good Friday	+ 0·6	Sunday.	+ 7·3	+ 4·9	− 6·3	+ 1·9	Sunday.	−1·3
	22	32·6	+ 3·8	+ 0·1	−11·5	− 5·4	+ 2·5	Sunday.	− 0·8	+ 1·9	0·0	+ 0·5	+ 3·6	− 8·0	−1·2
	23	32·9	+ 4·9	+ 0·2	−20·3	− 6·0	Sunday.	+ 6·6	+ 3·1	+ 1·4	+ 9·1	− 1·6	Sunday.	− 6·0	−0·9
	24	33·3	+ 7·3	+ 2·0	−15·0	Sunday.	− 0·1	+ 6·5	+ 0·3	+ 3·1	+ 1·7	Sunday.	+ 6·4	− 5·3	+0·7
	25	33·7	+ 4·9	Good Friday	−12·7	+ 6·0	+ 4·3	+ 5·1	+ 4·2	+ 6·1	Sunday.	−10·1	− 2·8	− 7·7	−0·3
	26	34·1	+ 8·2	+ 6·0	Sunday.	+ 4·0	+10·6	+ 4·7	− 3·0	Sunday.	− 4·6	− 8·2	+ 8·3	− 1·3	+2·5
	27	34·5	+ 3·7	Sunday.	− 7·0	− 1·5	+10·3	+ 4·0	−12·8	− 0·2	− 4·6	− 4·9	+16·4	− 3·1	0·0
	28	34·8	Sunday.	− 0·8	− 4·0	+ 3·6	+ 8·7	+ 1·0	Sunday.	+ 4·6	+ 5·5	− 2·1	− 0·8	Sunday.	+1·7
	29	35·2	− 5·1	+ 2·8	− 7·4	− 7·7	+14·6	Sunday.	− 1·8	+ 8·2	+ 5·5	Good Friday	+ 4·0	− 1·9	+1·1
	30	35·6	−13·8	+10·2	−10·1	−14·8	Sunday.	− 0·9	−12·3	+ 4·2	+ 8·4	− 1·7	Sunday.	− 7·3	−3·8
	31	36·0	− 3·6	− 8·8	−10·4	Sunday.	+18·5	− 0·7	−17·4	+10·9	+ 3·5	Sunday.	+ 1·7	− 2·0	−0·8
April.	1	36°3	+ 2°7	− 0°6	− 9°3	− 3°6	+ 0°2	− 1°7	− 9°5	− 3°0	Sunday.	+ 1°3	+ 3°5	− 4°3	−2°2
	2	36·7	− 1·7	+17·5	Sunday.	+ 2·9	+ 1·9	− 1·6	Good Friday	Sunday.	+ 1·4	+ 4·5	+ 6·6	− 8·1	+2·6
	3	37·1	+ 1·3	Sunday.	− 7·2	+14·6	− 3·5	+ 1·1	− 1·5	+ 7·4	+ 8·6	+ 8·0	+ 1·6	− 9·5	+1·9
	4	37·4	Sunday.	0·0	− 4·6	+11·8	− 1·5	+ 5·4	Sunday.	+ 3·4	+ 6·9	+ 3·1	− 4·2	Sunday.	+2·3
	5	37·8	− 2·1	+ 2·6	− 3·0	Good Friday	−10·7	Sunday.	+ 0·5	− 2·0	− 0·9	− 1·6	− 1·9	− 6·2	−2·5
	6	38·1	− 2·1	+ 3·5	− 4·0	− 0·4	Sunday.	+ 8·6	+ 5·4	+ 3·0	Good Friday	− 1·4	Sunday.	− 5·8	+0·8
	7	38·5	− 3·0	+ 2·6	− 2·4	Sunday.	−13·6	+ 9·5	+ 6·0	+ 0·9	+11·5	Sunday.	+ 1·0	− 6·4	+0·6
	8	38·8	− 1·1	− 3·2	+ 3·0	+12·5	−13·6	− 3·6	+ 6·5	+ 6·0	Sunday.	−13·1	+ 3·2	− 4·3	−0·7
	9	39·1	Good Friday	− 0·2	Sunday.	+ 9·2	− 3·8	− 0·4	+ 0·9	Sunday.	+ 2·7	−10·4	+ 0·7	− 3·4	−0·5
	10	39·5	−12·7	Sunday.	− 3·0	+11·4	+ 1·4	Good Friday	+ 2·0	+15·3	+ 6·0	− 7·4	− 3·2	− 3·4	+0·6
	11	39·8	Sunday.	+ 9·8	− 0·3	+10·6	− 4·9	+ 2·4	Sunday.	+ 6·5	− 3·8	−10·3	− 8·2	Sunday.	+0·2
	12	40·2	− 5·1	0·0	+ 0·9	+14·2	+ 0·3	Sunday.	+ 0·1	+ 7·2	− 3·9	− 4·1	− 8·0	− 0·3	+0·1
	13	40·5	− 2·9	− 3·2	− 1·2	+17·0	Sunday.	− 8·9	− 0·7	− 2·1	− 2·6	− 9·3	Sunday.	− 2·8	−1·7
	14	40·8	− 8·5	− 1·3	Good Friday	Sunday.	+ 6·5	− 2·9	− 1·7	+ 0·2	−16·7	Sunday.	− 1·6	+ 0·3	−2·9
	15	41·1	− 7·0	− 3·2	+ 5·1	+11·1	+ 9·4	− 9·5	− 8·6	+ 8·0	Sunday.	− 9·5	− 1·9	+ 2·5	−0·4
	16	41·5	− 0·2	− 2·8	Sunday.	+ 9·4	+ 1·3	− 3·1	− 6·5	Sunday.	− 9·9	−14·3	+ 3·4	+ 2·0	−2·1
	17	41·8	+ 6·8	Sunday.	+ 0·2	− 1·8	+ 0·1	+ 6·7	−11·8	− 2·2	− 3·3	−14·9	+ 0·8	+ 2·7	−1·5
	18	42·1	Sunday.	− 2·4	− 6·5	− 3·2	+ 2·0	+ 8·9	Sunday.	−11·8	− 5·8	− 9·6	Good Friday	Sunday.	−3·6
	19	42·4	− 3·8	+ 1·6	− 2·9	+ 1·5	0·0	Sunday.	− 5·1	− 9·5	− 4·1	− 2·6	− 3·4	+ 4·6	−2·2
	20	42·8	−11·4	+ 5·2	− 1·2	+ 5·6	Sunday.	+ 8·3	− 0·1	− 1·6	− 8·3	− 5·1	Sunday.	+ 1·3	−0·7
	21	43·1	− 4·7	+11·9	+ 4·9	Sunday.	− 1·3	+14·3	+12·4	Good Friday	− 7·5	Sunday.	− 2·0	+ 4·5	+3·6
	22	43·4	− 2·4	+18·3	+ 4·8	+ 6·5	+ 4·2	+ 3·1	− 0·6	+ 0·2	Sunday.	+ 6·3	+ 3·7	− 2·7	+3·8
	23	43·7	+ 2·4	− 1·7	Sunday.	+11·4	+11·6	+ 9·4	− 7·1	Sunday.	− 2·9	− 8·9	+ 4·8	−10·0	+0·9
	24	44·0	+ 7·3	Sunday.	+ 5·8	+11·3	+12·0	+ 7·3	− 5·2	− 6·9	− 6·3	− 1·6	+ 5·7	− 5·5	+2·2
	25	44·4	Sunday.	+ 3·1	+ 2·3	+ 5·7	− 1·2	− 2·4	Sunday.	− 4·5	− 0·7	+ 2·9	+ 5·5	Sunday.	+1·2
	26	44·7	+ 4·4	+ 1·1	+ 6·2	− 2·4	+ 3·9	Sunday.	+ 6·1	− 6·2	− 8·6	+ 4·4	+ 0·5	− 5·9	+0·3
	27	45·0	− 4·2	− 4·2	+ 2·8	− 5·2	Sunday.	+ 4·0	− 8·2	− 1·7	− 7·1	+ 8·1	Sunday.	− 6·4	−2·2
	28	45·4	− 0·5	− 4·2	+ 9·7	Sunday.	+ 7·5	+ 7·1	− 8·7	− 1·6	+ 2·5	Sunday.	− 1·5	− 6·3	+0·4
	29	45·7	− 2·5	− 1·7	− 8·0	+ 2·3	+ 7·3	+ 2·0	− 7·5	− 2·8	Sunday.	− 2·5	− 0·4	− 2·3	−1·5
	30	46·0	+ 0·6	+ 2·6	Sunday.	+ 6·3	+ 7·3	+ 6·0	− 7·7	Sunday.	+ 2·1	+ 2·7	− 2·1	− 1·5	+1·6

Table IV. (Continued.)

		Daily temperature derived from the monthly mean of the 12 years.	Difference on each day of the twelve years from the temperature derived from the monthly means.												Mean daily difference.
			1841.	1842.	1843.	1844.	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	
		(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)	(9.)	(10.)	(11.)	(12.)	(13.)	(14.)
May.	1	46·4	− 3·2	Sunday.	− 7·9	+11·6	+ 9·3	+ 7·5	Not obs.	− 3·7	− 3·9	− 7·9	− 6·6	− 0·9	−0·6
	2	46·7	Sunday.	− 1·1	− 6·0	+12·7	+ 1·3	+ 7·3	Sunday.	+ 0·6	− 7·9	− 4·2	− 9·4	Sunday.	−0·7
	3	47·0	−14·6	+ 0·6	− 2·1	+ 8·5	+ 6·9	Sunday.	Not obs.	+ 5·4	− 7·2	− 0·2	− 8·7	− 0·6	−1·2
	4	47·4	− 8·7	− 2·5	− 6·7	+ 2·3	Sunday.	+ 7·4	− 1·0	+ 6·0	− 0·6	− 1·9	Sunday.	− 4·6	−1·0
	5	47·7	− 7·1	+ 1·5	− 7·3	Sunday.	− 6·9	+ 7·8	− 0·3	+12·8	−10·2	Sunday.	− 5·8	+ 4·2	−1·1
	6	48·0	− 5·8	+ 4·2	− 1·5	+ 2·6	− 3·2	+ 2·3	+ 1·3	+14·7	Sunday.	− 5·6	− 5·4	+ 6·1	+0·9
	7	48·4	− 6·4	− 4·8	Sunday.	+ 7·3	− 8·3	+ 4·4	+ 7·7	Sunday.	− 5·9	− 2·1	− 1·1	+ 8·0	−0·1
	8	48·7	− 2·7	Sunday.	− 2·4	+ 6·3	− 5·9	+ 8·6	+ 6·4	+ 2·0	− 3·6	+ 0·3	+ 3·7	+10·1	+2·1
	9	49·1	Sunday.	− 6·8	+ 0·7	+ 1·0	− 1·2	+ 5·2	Sunday.	+ 3·1	− 2·9	− 7·6	+10·5	Sunday.	+0·2
	10	49·4	− 1·6	+ 6·1	+ 1·3	− 2·5	+ 1·9	Sunday.	+ 6·8	+ 1·1	− 4·3	− 8·6	+ 2·2	− 2·4	0·0
	11	49·8	+ 4·8	− 3·7	+ 3·4	+ 9·0	Sunday.	− 8·1	+ 7·5	− 2·0	− 5·1	− 7·4	Sunday.	+ 0·5	−0·1
	12	50·1	− 2·0	− 2·7	+ 6·3	Sunday.	+14·7	− 0·2	+10·0	− 5·3	− 3·4	Sunday.	+ 9·9	+ 4·1	+3·1
	13	50·5	− 5·1	− 6·9	+ 8·9	− 7·1	+12·1	+ 8·9	+ 6·7	−10·8	Sunday.	+ 7·0	+10·3	+ 2·8	+2·4
	14	50·8	− 6·8	− 6·7	Sunday.	− 0·8	+ 7·9	+11·2	+ 2·8	Sunday.	− 4·0	− 0·3	+ 0·6	+ 2·5	+0·6
	15	51·2	− 4·1	Sunday.	+11·5	+ 3·6	−10·7	+ 1·1	+ 7·5	− 2·0	− 3·6	+ 5·3	− 0·8	− 1·3	+0·6
	16	51·5	Sunday.	+ 1·8	+ 1·3	+ 3·0	−10·3	+ 2·9	Sunday.	− 0·3	+ 1·0	+ 4·7	+ 5·7	Sunday.	+1·1
	17	51·9	+ 3·1	+ 0·3	− 6·4	+ 1·7	− 0·3	Sunday.	+ 5·8	+ 2·4	+ 1·4	− 7·3	+ 5·2	− 5·0	+0·1
	18	52·2	+ 1·1	+ 8·2	− 3·6	− 1·6	Sunday.	− 5·1	+ 6·3	+ 8·6	+ 1·9	− 7·5	Sunday.	− 6·9	+0·1
	19	52·5	− 4·3	− 6·6	− 3·3	Sunday.	+ 3·9	− 6·5	+ 6·8	+ 9·9	+ 2·0	Sunday.	− 0·6	− 6·9	−0·6
	20	52·9	+ 1·4	− 9·3	− 0·2	− 5·3	− 5·9	+ 1·2	+ 1·2	+ 9·7	Sunday.	−15·8	+ 7·3	−11·8	−2·5
	21	53·2	+ 5·2	− 2·3	Sunday.	−12·5	− 2·7	−10·2	+ 1·7	Sunday.	+ 5·7	− 9·6	+ 1·5	− 0·4	−2·4
	22	53·6	+ 3·6	Sunday.	− 1·5	− 6·3	−10·3	− 1·8	+ 6·1	+ 3·5	− 1·0	− 8·0	+ 0·3	+ 2·9	−1·1
	23	53·9	Sunday.	− 1·6	− 3·5	+ 1·6	− 3·1	+ 5·2	Sunday.	+ 2·7	− 0·6	− 2·9	− 8·7	Sunday.	−1·2
	24	54·2	+ 8·3	− 3·2	− 0·1	+ 5·5	−10·8	Sunday.	+ 2·7	+ 6·7	−11·7	+ 3·4	− 7·1	+ 7·5	+0·1
	25	54·6	+ 6·0	− 2·6	− 1·3	+11·4	Sunday.	+11·3	+ 0·1	+ 7·0	− 9·2	− 0·7	Sunday.	− 1·5	+2·1
	26	54·9	+ 4·3	− 1·7	− 2·0	Sunday.	+ 7·3	+11·8	− 8·3	+ 1·6	− 4·8	Sunday.	+ 2·7	− 4·3	+0·7
	27	55·2	+ 3·6	− 5·8	− 3·9	+ 7·2	+ 5·4	+12·5	− 3·0	+ 2·5	Sunday.	−17·6	+ 0·4	− 3·7	−0·2
	28	55·6	+ 8·6	− 3·9	Sunday.	+ 4·2	− 2·7	+ 7·3	+ 7·2	Sunday.	− 1·2	+ 8·0	+ 2·2	− 0·5	+2·9
	29	55·9	+ 0·6	Sunday.	− 2·7	+ 1·6	−18·3	+ 8·5	+ 1·2	+ 7·4	− 2·4	+ 3·1	− 6·6	+ 5·4	−0·2
	30	56·2	Sunday.	− 6·2	−13·6	+ 1·3	−12·4	+ 8·7	Sunday.	− 1·6	− 4·7	− 8·6	− 4·0	Sunday.	−4·6
	31	56·5	+ 0·7	− 2·2	−16·2	− 1·9	− 3·1	Sunday.	−10·4	− 7·9	− 3·0	− 8·2	+ 0·9	− 2·9	−4·9
June.	1	56·9	+ 3·7	− 3·4	−16·8	+ 2·9	Sunday.	+ 8·0	− 2·6	− 4·2	− 2·2	− 4·1	Sunday.	− 2·0	−2·1
	2	57·2	+ 6·9	+ 1·2	−13·8	Sunday.	+ 5·1	+ 2·7	− 2·8	+ 5·6	− 0·3	Sunday.	− 2·6	+10·3	+1·3
	3	57·5	− 1·0	− 1·3	− 9·6	− 4·4	+ 5·4	+ 5·4	− 1·7	+ 6·6	Sunday.	+ 4·2	− 7·1	+ 3·5	0·0
	4	57·8	+ 9·5	+ 0·8	Sunday.	− 2·4	+ 6·5	+ 3·5	− 6·6	Sunday.	+ 1·6	+ 6·4	− 3·2	− 7·0	+0·9
	5	58·1	+12·7	Sunday.	−11·1	+ 1·8	− 1·6	− 5·3	− 5·4	− 1·5	− 4·2	+ 5·6	− 5·4	− 5·0	−2·2
	6	58·4	Sunday.	−12·6	−11·3	+ 3·4	− 6·6	− 7·9	Sunday.	− 8·4	− 1·7	+12·9	− 5·4	Sunday.	−4·2
	7	58·7	+11·6	− 8·8	− 7·1	− 4·6	− 5·1	Sunday.	+ 1·2	− 3·6	− 1·3	+13·0	− 1·8	− 1·9	−0·8
	8	59·0	+13·8	−10·7	− 5·5	− 6·9	Sunday.	− 2·9	− 1·8	− 0·8	− 5·5	+ 7·3	Sunday.	− 1·7	−1·5
	9	59·4	+ 6·8	− 4·0	+ 3·1	Sunday.	+10·2	− 1·0	+ 7·4	+ 6·2	− 3·6	Sunday.	− 5·9	− 1·9	+1·7
	10	59·7	+10·8	−17·9	−12·1	− 10·4	+ 6·7	+ 4·0	+ 2·1	+ 4·7	Sunday.	− 4·3	− 2·7	−11·7	−2·8
	11	59·9	+ 6·0	−23·2	Sunday.	− 7·8	+ 3·6	+ 0·2	− 3·5	Sunday.	− 2·6	− 3·7	− 2·1	− 5·9	−3·9
	12	60·2	− 6·4	Sunday.	− 3·2	− 4·7	+ 4·9	− 3·0	− 2·5	−10·6	− 7·0	+ 6·3	− 3·0	− 4·5	−3·1
	13	60·5	Sunday.	− 7·5	− 2·2	− 3·0	+ 2·6	− 1·2	Sunday.	− 8·0	− 0·8	+ 4·0	− 4·1	Sunday.	−2·2
	14	60·8	− 0·7	− 6·4	− 3·3	− 0·2	+ 3·9	Sunday.	−14·8	− 5·0	+ 0·1	+ 4·2	− 1·9	+ 9·5	−1·3
	15	61·1	− 4·2	− 2·9	− 8·6	+ 0·3	Sunday.	+ 7·7	−12·0	+16·8	+ 3·8	− 1·2	Sunday.	+13·2	+1·3
	16	61·3	− 1·5	− 0·7	− 4·9	Sunday.	− 8·7	+ 0·9	−10·6	+14·1	+ 3·0	Sunday.	− 3·9	+12·9	+0·1
	17	61·6	− 2·7	− 5·2	− 3·5	+ 2·1	− 7·4	+ 4·8	− 6·3	+10·7	Sunday.	+ 1·3	− 4·8	+ 6·4	−0·4
	18	61·9	− 2·8	+ 0·3	Sunday.	+ 8·2	− 4·3	+ 7·1	− 2·4	Sunday.	+ 4·8	+ 9·9	− 3·8	+ 5·1	+2·2
	19	62·1	+ 0·4	Sunday.	− 3·7	+ 5·0	− 2·6	+ 7·3	− 5·1	+ 6·1	+ 9·2	+11·0	+ 1·2	+ 0·4	+2·7
	20	62·4	Sunday.	− 6·7	+ 3·1	− 0·8	+ 1·6	− 6·2	Sunday.	+ 1·5	+12·2	+ 8·4	+ 2·8	Sunday.	+1·8
	21	62·6	+ 2·3	− 2·0	+ 6·2	− 2·4	+ 0·4	Sunday.	− 3·2	− 0·7	+12·0	+ 4·8	+ 0·2	+ 0·5	+1·6
	22	62·9	+ 7·7	− 1·3	+ 6·4	− 3·0	Sunday.	− 2·9	− 4·0	+ 1·1	+ 8·1	+ 0·3	Sunday.	− 2·5	+1·0
	23	63·1	+ 7·2	− 6·5	+ 4·2	Sunday.	+ 5·5	+ 3·6	− 0·7	+ 1·0	+ 5·0	Sunday.	+ 0·2	− 4·6	+1·5
	24	63·3	+ 3·5	− 5·0	+ 2·5	+ 3·9	+ 5·6	+ 6·5	+ 1·6	+ 0·3	Sunday.	− 0·6	− 1·7	− 8·7	+0·7
	25	63·5	+ 3·0	− 7·2	Sunday.	+ 6·2	− 6·0	+ 8·8	+ 1·9	Sunday.	+ 3·3	− 4·1	+ 0·5	− 5·7	+0·1
	26	63·8	+ 5·9	Sunday.	+ 3·5	− 0·9	− 3·7	+ 6·1	+ 5·6	+ 5·9	+ 4·9	− 0·3	+ 4·0	+ 0·1	+2·8
	27	64·0	Sunday.	− 2·5	+ 7·2	− 3·4	− 0·2	+ 1·4	Sunday.	+ 6·3	+ 6·8	− 3·4	+ 0·3	Sunday.	+1·4
	28	64·2	+ 7·5	− 3·4	+ 3·9	− 4·2	− 7·5	Sunday.	+ 1·6	+ 1·5	+ 2·1	+ 0·3	+ 1·3	− 1·1	+0·2
	29	64·4	+14·3	− 3·3	+ 3·0	− 3·3	Sunday.	+ 5·1	− 1·0	+ 0·2	+ 2·9	+ 4·2	Sunday.	− 1·1	+2·1
	30	64·5	+ 6·2	+ 1·3	+ 5·8	Sunday.	− 9·8	+ 8·1	− 1·7	+ 4·2	+ 5·0	Sunday.	+ 2·8	− 0·8	+2·1

Table IV. (Continued.)

	Daily temperature derived from the monthly means of the 13 years.	Difference on each day of the twelve years from the temperature derived from the monthly means.												Mean daily difference.
		1841.	1842.	1843.	1844.	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	
	(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)	(9.)	(10.)	(11.)	(12.)	(13.)	(14.)
July. 1	64°7	+3°0	−5°6	+10°4	+4°1	−8°3	+5°5	+1°3	−8°5	Sunday.	+3°1	−4°0	−7°7	−6°6
2	64·9	−5·1	−5·6	Sunday.	+1·4	−7·2	+1·8	+3·1	Sunday.	−3·7	+3·5	−7·3	−6·1	−2·5
3	65·1	−5·4	Sunday.	−7·5	−6·4	−7·8	−1·9	+5·9	−5·6	−2·7	+5·0	−8·0	−6·0	−3·7
4	65·2	Sunday.	−3·3	−2·7	−9·6	−8·2	+2·9	Sunday.	−4·4	−0·7	+4·9	−2·8	Sunday.	−2·6
5	65·3	+2·3	−7·9	−5·2	−5·4	−2·5	Sunday.	+6·8	−2·7	−1·8	+4·7	−0·6	−2·0	−1·3
6	65·5	−4·9	−10·1	−0·9	+4·1	Sunday.	+4·1	+3·6	−1·1	+0·1	+1·3	Sunday.	+2·0	−0·2
7	65·6	−4·6	−5·6	−0·3	Sunday.	+5·5	+1·1	+5·9	−4·1	+4·0	Sunday.	−4·0	+7·3	+0·5
8	65·7	−1·3	−5·5	+4·6	−3·1	+4·8	+2·9	+7·9	−8·4	Sunday.	−2·5	−5·2	+10·2	+0·4
9	65·9	−1·4	−6·2	Sunday.	+2·0	−3·2	+6·7	+7·6	Sunday.	+6·6	−2·2	+0·5	+3·6	+1·4
10	66·0	−5·1	Sunday.	−4·0	+2·8	−0·5	+12·5	+6·4	−2·6	+10·8	−0·5	−2·0	+6·0	+2·2
11	66·1	Sunday.	−3·5	−10·7	+1·1	+7·1	+8·9	Sunday.	+0·9	+10·7	+3·0	−3·9	Sunday.	+1·5
12	66·2	−0·9	+2·4	−6·4	+1·7	+15·8	Sunday.	+8·1	+2·1	+12·6	+6·6	−2·0	−3·8	+3·3
13	66·3	+3·2	+4·7	−3·2	+1·1	Sunday.	−3·0	+4·0	+5·2	+12·1	+1·2	Sunday.	−2·8	+2·2
14	66·3	+6·3	+2·0	+2·7	Sunday.	+9·7	−10·2	−3·6	+4·2	−4·6	Sunday.	+2·3	+0·8	+1·0
15	66·4	−2·0	−1·4	−1·2	−3·1	+8·2	−9·2	+1·2	−0·5	Sunday.	+8·4	−0·6	−0·7	−0·1
16	66·5	−5·9	+0·1	Sunday.	−3·5	+10·7	−8·3	+7·0	Sunday.	−1·6	+6·8	+6·1	−1·5	+1·0
17	66·6	−4·4	Sunday.	+1·1	−2·6	+7·0	−5·2	+8·0	−2·6	+0·8	+5·2	+6·2	+2·6	+1·5
18	66·6	Sunday.	+5·4	+5·2	+1·1	−0·5	−1·8	Sunday.	+2·9	+3·6	−2·2	−1·5	Sunday.	+1·4
19	66·7	+1·7	+4·8	−6·9	+0·2	−2·5	Sunday.	+10·6	+3·0	+7·2	−0·9	−3·3	−5·6	+0·8
20	66·7	+0·6	−6·0	−9·4	−1·7	Sunday.	+5·9	+7·0	+6·5	+2·5	+3·0	Sunday.	+2·4	+1·1
21	66·7	+4·4	−6·9	−4·3	Sunday.	+6·4	+2·6	+6·0	+3·9	−0·4	Sunday.	−2·2	+10·0	+1·9
22	66·8	+8·7	+0·3	+0·3	+3·9	+0·8	−1·1	+0·2	−3·6	Sunday.	+3·2	−0·2	+8·0	+1·9
23	66·8	+7·1	+4·5	Sunday.	+1·2	−4·7	+4·8	−3·0	Sunday.	−1·7	+2·6	+2·9	+2·3	+1·6
24	66·8	+4·3	Sunday.	+0·1	−1·9	−6·8	−0·8	−2·9	+0·3	+2·3	+8·2	−0·9	−1·2	+0·1
25	66·9	Sunday.	−6·9	−2·5	−3·9	−2·1	+4·8	Sunday.	−3·1	0·0	−1·1	+2·8	Sunday.	−1·3
26	66·9	−3·8	+4·8	+0·7	−5·0	+0·8	Sunday.	−12·5	−0·2	+3·1	−7·5	+4·9	+0·8	−1·4
27	66·9	−4·0	+4·0	−1·8	−2·8	Sunday.	−0·7	−10·8	−1·3	−4·6	−7·1	Sunday.	−3·9	−3·3
28	66·9	−9·5	−2·6	+3·9	Sunday.	−3·8	+2·1	−8·5	−1·6	−2·7	Sunday.	−0·2	−0·1	−2·3
29	66·9	−4·7	+3·9	−7·1	+3·6	−5·2	+8·5	−2·6	−3·2	Sunday.	+4·6	−5·2	+6·0	−0·1
30	66·9	−8·8	−5·7	Sunday.	+2·4	−11·4	+8·0	−7·5	Sunday.	+4·6	+1·1	−5·3	−0·6	−2·3
31	66·9	−8·4	Sunday.	−5·6	+5·3	−7·9	+1·0	−5·9	0·0	−6·0	+1·9	−4·2	−10·5	−3·7
August. 1	66·9	Sunday.	−11·0	−8·2	+1·2	−7·8	+2·0	Sunday.	−5·9	−3·9	+3·0	−5·1	Sunday.	−4·0
2	66·8	−4·2	−7·7	−6·5	−1·3	−5·4	Sunday.	−4·0	+1·3	−0·4	+3·1	−2·5	−9·4	−3·6
3	66·8	+1·2	−7·7	−2·1	−3·7	Sunday.	+3·2	−3·6	+1·2	+3·0	+1·8	Sunday.	−5·8	−1·3
4	66·8	+0·3	−4·5	+1·4	Sunday.	−0·2	+8·4	−0·6	+0·2	−1·8	Sunday.	−4·4	−2·9	−0·4
5	66·8	−1·6	+0·2	+2·0	−3·0	+1·4	+11·6	+0·5	−3·0	Sunday.	+6·2	−2·9	−4·0	+0·7
6	66·8	−3·8	−3·8	Sunday.	−4·2	+1·5	+6·1	+2·2	Sunday.	+0·3	+5·2	−0·2	−4·5	−0·1
7	66·7	−3·5	Sunday.	+2·5	−0·4	+5·2	+5·9	−2·3	−1·9	−1·8	+6·6	+2·4	+0·2	+1·2
8	66·7	Sunday.	−1·0	−0·7	+3·2	+2·4	+0·4	Sunday.	−0·1	−0·7	+3·3	−2·4	Sunday.	+0·5
9	66·6	−1·8	−3·7	−2·4	+3·1	+5·8	Sunday.	+11·4	+5·1	+0·8	+4·1	−3·7	−1·0	+1·6
10	66·6	−3·8	−2·6	+0·8	−3·3	Sunday.	+0·5	+3·6	+7·4	−7·2	−0·4	Sunday.	−2·8	−0·8
11	66·5	−8·1	−1·5	+1·1	Sunday.	+2·1	−2·6	−1·0	+6·9	−4·6	Sunday.	−1·3	−3·3	−1·2
12	66·4	−5·9	+1·7	+3·9	−8·1	−0·5	+5·8	+1·9	+6·3	Sunday.	+6·7	+2·1	−1·3	+1·1
13	66·3	−1·7	+0·3	Sunday.	−4·3	−3·3	+6·6	+4·2	Sunday.	−0·5	−2·6	+2·6	+0·2	+0·2
14	66·3	−5·2	Sunday.	+2·2	−2·1	−2·1	+3·2	+4·9	+11·3	−3·3	−2·2	−7·3	+2·7	+0·2
15	66·2	Sunday.	+1·6	−2·2	+0·5	+0·1	+6·6	Sunday.	+6·7	−4·3	−5·5	−8·8	Sunday.	−0·6
16	66·1	+1·9	+3·5	+3·6	+4·7	+2·9	Sunday.	+7·0	+4·8	−1·9	−5·9	−6·7	−8·6	+0·5
17	66·0	+4·0	+3·9	+2·0	+1·0	Sunday.	−2·7	+0·7	−2·6	+0·6	−7·1	Sunday.	−4·4	−0·5
18	65·9	+4·3	+2·3	−3·2	Sunday.	+6·3	−8·7	−9·1	+0·1	+3·9	Sunday.	−6·0	0·0	−1·0
19	65·8	−1·4	−1·5	−4·5	+4·8	+1·1	−2·6	−8·1	−0·3	Sunday.	−2·1	−6·3	+5·3	−1·4
20	65·6	−0·8	−5·3	Sunday.	−2·6	+4·4	−2·2	−4·7	Sunday.	+2·9	−3·6	−4·3	+2·5	−1·2
21	65·5	+1·3	Sunday.	−4·3	−4·7	+6·9	+2·0	−2·3	−2·0	+3·8	−2·8	+0·5	+3·3	+0·2
22	65·4	Sunday.	−2·7	−3·0	+0·2	+3·1	−0·5	Sunday.	+1·2	+0·9	−1·6	+2·7	Sunday.	0·0
23	65·2	−6·5	−0·2	−2·2	−3·0	+7·2	Sunday.	−5·7	+4·6	+2·7	+1·2	+2·1	+7·8	+0·7
24	65·0	−5·6	+1·8	−3·1	−6·5	Sunday.	−4·6	−3·6	+3·3	+2·6	+1·9	Sunday.	+7·2	−0·7
25	64·8	−2·6	+6·6	−0·5	Sunday.	+4·0	+0·4	−2·9	+3·1	+4·8	Sunday.	−0·8	+6·4	+1·9
26	64·6	−2·7	+6·8	+4·8	−6·7	+3·0	+1·3	+1·6	+2·7	Sunday.	−3·9	−8·7	+6·6	+0·4
27	64·4	−0·9	+6·0	Sunday.	−7·4	−3·6	+3·2	−6·3	Sunday.	+4·2	−9·8	−9·3	−1·0	−2·5
28	64·2	+1·4	Sunday.	+3·7	−5·7	−1·6	+3·7	−3·8	+5·7	−2·5	−2·7	−5·5	−3·1	−0·9
29	63·9	Sunday.	+1·7	+3·1	−4·7	+6·2	+2·4	Sunday.	+3·8	+4·2	+0·1	−1·3	Sunday.	+1·7
30	63·7	−0·6	−1·1	+6·9	−1·6	+3·3	Sunday.	−0·9	+6·0	+6·7	+4·1	+5·3	−1·0	+2·5
31	63·4	−0·2	+4·3	+10·1	+1·5	Sunday.	+8·0	−8·9	+6·4	−5·8	+7·3	Sunday.	+2·9	+2·6

Table IV. (Continued.)

		Daily temperature derived from the monthly mean of the 12 years.	Difference on each day of the twelve years from the temperature derived from the monthly means.												Mean daily difference.
			1841.	1842.	1843.	1844.	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	
		(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)	(9.)	(10.)	(11.)	(12.)	(13.)	(14.)
September.	1	63·1	+ 4·1	+10·7	+ 8·5	Sunday.	+ 6·7	+10·8	+ 5·2	+ 1·8	− 8·1	Sunday.	+ 6·8	+ 7·8	+ 4·2
	2	62·8	+ 7·1	+ 0·6	+ 9·7	+ 4·2	+ 2·0	+11·6	+ 0·2	+ 1·0	Sunday.	− 3·6	+ 1·7	+ 8·8	+3·9
	3	62·5	+ 5·7	− 6·0	Sunday.	+ 0·4	+ 4·6	+ 8·3	+ 0·5	Sunday.	− 2·2	− 0·5	0·0	+ 1·8	+1·3
	4	62·2	+ 4·6	Sunday.	+ 7·5	− 1·5	+ 2·4	+10·8	− 5·8	+ 7·9	+ 3·7	+ 2·7	+ 1·4	− 2·5	+2·8
	5	61·9	Sunday.	− 2·7	+ 1·3	− 3·2	− 3·8	+ 9·7	Sunday.	+ 1·0	+ 6·9	− 2·4	+ 5·4	Sunday.	+1·4
	6	61·5	+ 6·9	− 1·0	+ 4·6	+ 0·1	− 2·3	Sunday.	− 2·9	− 4·0	− 5·4	− 3·7	+ 6·3	+ 4·9	+0·3
	7	61·2	+ 8·1	+ 2·0	+ 4·9	+ 0·2	Sunday.	+12·5	+ 1·7	− 0·9	−11·0	− 0·7	Sunday.	+ 4·5	+2·1
	8	60·8	+ 8·4	− 6·3	+ 1·1	Sunday.	− 8·9	+ 1·4	+ 3·9	+ 2·0	−10·0	Sunday.	+10·1	+ 3·8	+0·6
	9	60·4	+ 9·4	− 8·1	− 7·7	+ 3·7	− 3·6	+ 0·3	− 7·7	− 4·7	Sunday.	− 2·6	+ 9·2	+ 7·1	−0·4
	10	60·1	+ 8·2	− 3·7	Sunday.	+ 4·5	− 6·7	+ 3·8	− 5·2	Sunday.	− 3·5	− 2·8	+13·7	+ 9·0	+1·7
	11	59·7	− 3·5	Sunday.	− 8·6	+ 4·5	− 8·2	+10·7	− 4·6	− 1·4	− 0·5	− 5·7	+13·3	+ 4·7	+0·1
	12	59·3	Sunday.	− 0·9	− 7·9	+ 2·7	− 7·4	+ 9·3	Sunday.	− 7·1	+ 2·3	−11·6	+15·6	Sunday.	−0·6
	13	58·9	− 3·2	− 1·4	− 1·7	+ 0·7	− 3·7	Sunday.	− 9·6	− 5·9	+ 3·1	− 8·2	− 3·0	−11·5	−4·0
	14	58·4	− 3·9	− 0·4	− 2·6	+ 7·0	Sunday.	+14·7	−12·7	− 3·3	+ 4·1	− 8·7	Sunday.	− 9·0	−1·5
	15	58·0	+ 3·0	+ 1·8	+ 3·0	Sunday.	− 1·0	− 1·2	− 9·3	− 8·6	+ 5·0	Sunday.	−10·5	− 9·4	−2·7
	16	57·6	+ 5·7	− 2·5	+ 3·5	+ 8·1	− 9·2	+ 1·5	− 5·4	− 6·9	Sunday.	− 2·1	− 7·0	− 8·9	−2·1
	17	57·1	+ 3·8	− 3·5	Sunday.	+10·9	+ 1·4	+ 1·2	+ 1·2	Sunday.	+ 4·7	+ 2·8	− 5·2	− 5·9	+1·1
	18	56·7	− 6·7	Sunday.	+ 5·8	+ 1·9	+ 3·5	+ 2·0	+ 1·4	− 0·1	− 1·0	+ 2·9	+ 1·4	− 0·1	+1·0
	19	56·2	Sunday	−10·0	+ 2·9	+ 8·7	− 1·3	+ 6·9	Sunday.	+ 3·1	− 4·0	− 3·0	+ 5·9	Sunday.	+1·0
	20	55·7	+ 4·3	− 2·2	+ 4·9	+13·9	− 3·6	Sunday.	− 0·8	− 4·1	+ 0·7	− 2·2	+ 9·7	− 2·8	+1·6
	21	55·2	+ 8·0	−11·4	+12·2	+ 2·8	Sunday.	− 3·6	− 1·9	− 9·5	+ 4·6	+ 1·7	Sunday.	+ 5·5	+0·8
	22	54·7	+11·1	−17·6	− 0·1	Sunday.	− 6·0	− 0·9	− 2·3	−14·3	+ 7·6	Sunday.	− 2·7	− 1·7	−2·7
	23	54·3	+ 7·4	−10·5	+11·4	− 5·9	− 5·1	+10·2	+ 5·7	− 4·9	Sunday.	+12·5	+ 4·4	− 4·3	+1·9
	24	53·8	+ 6·3	− 7·0	Sunday.	− 5·4	− 6·1	+ 4·9	+ 0·1	Sunday.	+ 0·3	+ 8·3	−10·5	+ 0·9	−0·8
	25	53·3	+ 4·3	Sunday.	− 0·1	− 7·2	− 3·4	− 1·5	− 0·6	− 3·7	+ 6·9	− 2·2	− 4·6	+ 2·0	−0·9
	26	52·8	Sunday.	− 3·6	− 9·0	− 9·8	− 3·1	+ 0·3	Sunday.	−14·2	− 3·7	− 2·0	+ 3·8	Sunday.	−4·6
	27	52·3	− 2·6	+ 6·3	−11·6	−11·9	− 3·5	Sunday.	+ 7·2	− 5·2	− 4·8	0·0	− 7·7	− 5·7	−3·6
	28	51·9	− 2·0	+ 5·2	− 7·2	− 8·6	Sunday.	+ 1·2	− 2·8	− 8·0	+ 5·9	− 1·1	Sunday.	− 4·0	−2·1
	29	51·4	− 4·1	+ 6·1	+ 0·1	Sunday.	+12·1	+ 9·3	− 4·9	− 0·7	+ 2·8	Sunday.	+ 1·2	− 7·3	+1·4
	30	50·9	− 5·3	+ 5·3	+ 3·1	− 5·4	+ 6·7	+10·9	− 2·1	− 8·0	Sunday.	− 5·1	− 2·2	− 0·5	−0·2
October.	1	50·5	− 9·1	+ 5·3	Sunday.	− 6·2	− 0·2	− 0·5	− 4·7	Sunday.	− 1·9	+ 1·1	− 3·2	+ 3·0	−1·6
	2	50·0	− 6·7	Sunday.	+ 2·0	+ 4·4	+ 4·9	− 4·1	− 2·0	− 1·9	− 5·0	− 6·6	+ 3·4	+ 9·6	−0·2
	3	49·6	Sunday.	− 1·8	− 3·0	+ 1·3	+ 3·2	− 2·1	Sunday.	+ 5·0	− 0·5	− 3·4	+ 2·7	Sunday.	+0·2
	4	49·1	− 4·6	− 5·1	− 3·7	+ 1·2	+ 2·5	Sunday.	+ 6·0	+ 4·7	+ 1·6	+ 2·5	− 1·2	+ 5·9	+0·9
	5	48·7	− 2·7	− 4·8	+ 0·8	− 0·9	Sunday.	+ 3·7	+10·7	+ 4·0	− 1·3	+ 2·2	Sunday.	+ 2·6	+1·4
	6	48·3	− 2·2	− 3·7	+ 8·0	Sunday.	− 6·9	+ 7·4	+ 8·8	+ 0·3	− 0·9	Sunday.	+ 2·0	+ 9·0	+2·2
	7	47·9	0·0	+ 6·7	+ 5·1	−10·1	+ 1·9	+15·3	+ 7·8	+ 3·3	Sunday.	−10·2	+ 5·9	+ 6·7	+2·9
	8	47·5	− 2·2	+ 6·3	Sunday.	+ 4·8	+ 7·5	+11·5	+ 5·8	Sunday.	− 1·4	+ 0·9	+ 8·0	+ 9·2	+5·0
	9	47·1	− 1·6	Sunday.	− 3·5	+ 7·7	+ 8·4	+ 5·3	+ 4·0	+ 5·1	+ 3·6	+ 7·4	+ 8·3	+ 6·1	+4·6
	10	46·7	Sunday.	+ 1·0	− 0·7	+ 1·5	+10·4	− 6·0	Sunday.	− 1·8	− 2·2	+ 7·8	+ 9·1	Sunday.	+2·1
	11	46·3	+ 5·1	+ 9·3	+ 3·1	− 4·3	+ 6·1	Sunday.	− 2·8	− 6·1	+ 0·1	+ 7·7	+11·0	+ 3·6	+3·0
	12	46·0	− 2·4	+ 0·8	− 3·1	− 2·0	Sunday.	+10·3	− 2·9	− 3·9	+ 2·0	− 1·7	Sunday.	+ 1·5	−0·1
	13	45·6	− 4·1	0·0	− 7·4	Sunday.	+ 4·5	− 0·1	− 6·1	− 1·7	− 4·1	Sunday.	+ 9·7	− 4·4	−1·4
	14	45·3	+ 2·3	+ 1·0	− 8·5	+ 2·5	− 3·6	− 0·9	−10·8	+ 5·2	Sunday.	− 6·3	+ 2·3	− 1·7	−1·7
	15	44·9	+ 2·2	− 1·7	Sunday.	+ 0·2	− 9·9	− 0·8	− 4·5	Sunday.	+ 4·8	− 2·0	− 4·2	− 6·0	−2·2
	16	44·6	− 6·8	Sunday.	− 3·5	− 1·6	− 6·3	+ 5·0	+ 5·3	+10·6	+ 8·7	+ 8·7	− 8·0	− 8·0	+0·4
	17	44·3	Sunday.	− 0·1	+ 5·0	− 2·0	+ 3·0	−11·0	Sunday.	− 8·7	+ 5·1	+10·7	− 1·3	Sunday.	−1·7
	18	44·1	− 8·5	+ 5·8	− 3·4	+ 0·1	+ 3·8	Sunday.	+ 8·9	− 9·2	− 0·4	− 1·2	+ 8·6	+11·2	+0·4
	19	43·8	− 3·6	+ 5·1	− 3·6	− 6·1	Sunday.	− 1·1	− 0·9	− 3·3	− 3·7	− 2·4	Sunday.	− 0·4	−3·0
	20	43·6	− 4·2	− 6·2	+ 8·9	Sunday.	− 9·9	− 3·4	− 2·3	− 1·4	− 2·7	Sunday.	+ 9·7	− 1·7	−1·3
	21	43·3	+ 4·5	− 0·8	− 1·1	− 1·9	−14·7	− 5·0	− 2·2	− 3·3	Sunday.	+ 0·2	+ 1·6	+ 5·1	−2·4
	22	43·0	− 7·6	+ 3·5	Sunday.	+ 0·5	−12·0	−12·0	− 4·4	Sunday.	+ 6·0	+ 5·6	− 2·7	+ 2·1	−2·1
	23	42·8	− 9·0	Sunday.	−10·4	+ 0·1	− 1·2	− 6·4	− 0·8	− 0·7	+ 2·8	+ 2·0	− 2·2	− 2·6	−2·6
	24	42·5	Sunday.	+ 8·4	− 6·6	+ 5·4	+ 1·9	− 3·4	Sunday.	+ 5·3	− 2·3	− 1·0	+ 3·1	Sunday.	+1·2
	25	42·3	−11·2	− 1·4	− 5·5	+ 7·2	+ 2·6	Sunday.	− 3·5	+ 2·2	+ 3·3	− 3·1	− 6·4	+ 2·8	−1·2
	26	42·0	− 3·7	− 1·4	− 7·3	+ 0·6	Sunday.	+ 7·1	−15·4	− 0·4	+ 3·5	− 2·7	Sunday.	− 2·9	−2·3
	27	41·8	− 9·9	− 4·6	−10·8	Sunday.	+ 6·0	+ 1·0	−11·6	+ 3·0	+ 2·4	Sunday.	− 9·8	+ 5·6	−2·9
	28	41·5	− 5·2	+ 2·2	− 6·6	−13·5	+ 7·4	− 8·1	− 7·2	+ 7·4	Sunday.	+ 2·9	− 1·6	+11·1	−1·0
	29	41·3	+ 3·0	+ 2·4	Sunday.	−12·5	+12·8	− 1·0	− 1·5	Sunday.	+ 7·1	− 8·2	+ 8·1	+ 6·2	+1·6
	30	41·0	+ 8·5	Sunday.	− 9·1	−10·7	+11·1	− 5·4	+ 1·4	+ 9·7	− 3·9	− 4·1	+10·4	+ 5·4	+1·2
	31	40·8	Sunday.	− 1·4	− 7·7	−10·9	+11·9	− 5·1	Sunday.	+ 2·1	−10·9	+ 3·1	+ 1·4	Sunday.	−1·9

Table IV. (Continued.)

		Daily temperature derived from the monthly means of the 12 years.	Difference on each day of the twelve years from the temperature derived from the monthly means.											Mean daily difference.
			1841.	1842.	1843.	1844.	1845.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	
		(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)	(9.)	(10.)	(11.)	(12.)	(13.)	(14.)
November.	1	40°5	+13°2	+ 3°9	− 4°4	− 2°3	+ 7°8	Sunday.	+10°1	− 1°7	− 4°0	+ 6°8	+ 3°5	+ 3°5	+3°3
	2	40·3	+ 6·6	− 0·5	− 5·3	− 1·5	Sunday.	+ 9·8	+11·6	− 4·7	+ 1·2	+ 5·4	Sunday.	+ 3·1	+2·6
	3	40·0	+ 2·4	− 4·9	− 9·0	Sunday.	+ 1·5	+ 7·7	+10·8	− 0·3	+ 6·9	Sunday.	− 4·3	+ 0·5	+1·1
	4	39·8	− 3·2	− 4·6	−12·8	+ 0·5	+ 1·5	+ 4·9	+ 3·6	+ 3·3	Sunday.	+10·4	− 8·1	+ 1·2	−0·3
	5	39·5	− 2·2	+ 0·3	Sunday.	+ 0·4	+ 2·0	0·0	− 0·9	Sunday.	+13·8	+14·8	−11·0	− 0·3	+1·7
	6	39·2	− 6·2	Sunday.	− 9·4	− 0·2	+ 2·4	+ 2·0	− 6·2	− 2·8	+12·6	+ 4·2	− 7·9	+ 1·8	−0·9
	7	39·0	Sunday.	+ 5·4	− 5·2	+ 3·9	+ 0·7	+ 7·6	Sunday.	− 8·7	+10·1	− 4·7	− 1·9	Sunday.	+0·8
	8	38·7	− 0·7	+ 0·4	− 5·6	− 4·4	− 5·1	Sunday.	+ 9·4	− 8·6	+ 5·2	− 1·7	+ 0·5	− 0·9	−1·0
	9	38·4	− 1·1	− 2·1	− 3·2	− 4·5	Sunday.	+13·6	+ 7·9	−16·3	+ 6·2	− 3·1	Sunday.	− 3·0	−0·6
	10	38·1	+ 0·8	− 1·8	− 1·3	Sunday.	+ 1·1	+14·2	− 0·5	−12·6	+ 9·2	Sunday.	− 6·5	− 3·6	−0·1
	11	37·8	+ 4·3	+ 3·1	− 3·1	+ 3·2	+ 0·2	+12·2	− 1·8	− 9·0	Sunday.	− 0·5	−14·0	+ 1·1	−0·4
	12	37·5	+ 3·7	+ 1·3	Sunday.	+ 4·8	− 1·5	+ 9·2	− 0·7	Sunday.	+ 5·1	+ 1·4	− 6·8	+ 0·4	+1·7
	13	37·2	+ 0·9	Sunday.	− 9·5	− 3·7	+ 7·0	+ 8·7	+ 0·8	− 4·1	+ 9·0	− 0·8	− 5·6	− 4·3	−0·1
	14	36·9	Sunday.	+ 0·7	−11·8	− 2·9	+ 4·7	+ 7·5	Sunday.	− 0·2	+ 6·4	+ 3·1	− 5·0	Sunday.	+0·3
	15	36·5	− 6·4	− 3·1	− 0·9	− 0·3	+ 2·3	Sunday.	+ 0·6	+ 0·9	+ 0·8	+ 6·1	− 3·8	− 4·2	−0·7
	16	36·2	− 1·8	− 1·2	+ 2·7	+ 3·2	Sunday.	+ 8·4	+ 6·6	+ 0·6	+ 4·8	− 2·1	Sunday.	− 4·5	+1·7
	17	35·8	− 4·5	+ 2·2	+ 4·0	Sunday.	+ 9·6	+10·3	+11·7	− 2·1	+ 4·8	Sunday.	− 4·0	− 4·5	+2·8
	18	35·5	− 7·1	−14·0	+ 4·7	− 5·9	+14·3	+10·5	+ 7·9	− 4·9	Sunday.	+ 0·4	− 5·1	− 1·2	0·0
	19	35·1	− 4·9	− 6·8	Sunday.	+ 0·2	+ 4·6	+ 4·1	− 8·4	Sunday.	+10·5	+ 1·4	− 3·1	− 1·6	−0·4
	20	34·8	− 1·6	Sunday.	+ 3·6	+ 0·7	+ 8·9	+ 3·5	− 8·1	− 2·5	+ 9·9	+ 1·9	+ 1·4	+ 0·3	+1·6
	21	34·4	Sunday.	− 8·5	+ 4·4	+ 2·4	− 1·1	+ 6·1	Sunday.	− 0·8	+ 7·8	− 6·0	+ 3·8	Sunday.	+0·9
	22	34·1	+ 8·6	− 4·1	− 2·7	+ 7·3	+ 0·3	Sunday.	+ 7·4	− 0·2	+11·6	− 6·8	− 3·1	− 0·7	+1·6
	23	33·7	+ 1·4	0·0	+ 5·6	+ 4·3	Sunday.	+ 8·4	+ 0·7	+ 9·0	+ 8·5	Sunday.	− 4·9	− 7·6	+1·2
	24	33·3	+ 0·6	− 4·3	+ 6·5	Sunday.	− 8·4	+ 0·7	+11·7	+ 9·0	+ 8·5	Sunday.	− 4·9	− 7·6	+2·8
	25	33·0	− 5·2	− 5·1	+ 0·9	−12·3	+ 1·9	−12·8	+ 3·8	+ 1·3	Sunday.	+ 3·8	− 3·5	+ 3·5	−2·2
	26	32·6	−10·7	− 7·9	Sunday.	− 5·9	− 1·6	− 7·2	− 8·7	Sunday.	+ 7·7	+ 3·8	− 6·3	+ 7·4	−2·9
	27	32·2	− 8·9	Sunday.	−12·0	−15·7	−14·5	− 0·2	− 3·9	− 2·2	+ 2·7	+11·5	+ 1·8	+ 2·7	−3·5
	28	31·9	Sunday.	−12·9	− 6·0	−11·3	−18·1	+ 6·2	Sunday.	+ 7·0	− 1·3	+ 4·3	+ 3·3	Sunday.	−3·2
	29	31·5	−13·4	−11·4	− 1·5	− 0·9	−11·9	Sunday.	−17·9	+ 9·3	+ 0·3	+ 5·1	+ 3·4	+ 1·4	−3·4
	30	31·1	− 1·5	− 5·2	− 4·4	+ 3·6	Sunday.	− 7·4	− 5·9	− 2·0	+ 3·7	+ 5·6	Sunday.	+ 3·9	−1·0
December.	1	30·8	+ 3·1	− 5·7	− 0·2	Sunday.	−12·1	− 3·5	+ 6·1	− 3·6	− 9·4	Sunday.	− 9·2	+ 4·7	−3·0
	2	30·5	+ 4·7	+ 1·5	− 0·3	− 1·3	−22·3	+10·6	+ 4·4	+ 6·4	Sunday.	+ 1·2	− 7·9	+ 4·3	+0·1
	3	30·1	+ 9·5	+ 6·1	Sunday.	+ 2·7	− 9·8	+ 0·3	+ 0·5	Sunday.	− 0·1	+ 9·7	− 5·6	+10·5	+2·4
	4	29·8	+ 5·5	Sunday.	+ 5·4	+ 5·1	− 3·6	+ 2·4	− 0·3	+ 4·8	+ 4·1	+ 5·2	− 3·8	+11·3	+3·3
	5	29·4	Sunday.	− 4·1	− 9·5	+ 4·3	− 6·5	+ 2·0	Sunday.	+ 0·2	+ 5·3	+ 2·4	− 6·0	Sunday.	−1·3
	6	29·1	+ 0·4	−10·2	− 0·5	+ 6·6	− 6·1	Sunday.	+ 2·0	− 1·3	− 3·0	+ 0·6	+ 0·3	+14·5	+0·3
	7	28·7	+ 2·2	− 3·1	+ 1·1	+ 9·5	Sunday.	+ 9·7	+ 6·2	+ 4·1	− 4·4	− 6·5	Sunday.	+19·0	+3·8
	8	28·5	+10·7	+ 4·0	+ 1·5	Sunday.	+ 0·7	+ 6·5	+ 3·1	+12·2	− 4·1	Sunday.	+ 9·3	+10·5	+5·4
	9	28·2	+12·5	− 0·1	− 0·3	+ 0·1	+ 0·6	+ 3·3	+13·7	+ 4·5	Sunday.	− 2·9	+ 1·2	+ 8·4	+3·7
	10	27·9	+13·1	− 8·6	Sunday.	− 1·1	−13·8	+ 1·9	+14·5	Sunday.	+ 0·6	−10·2	+ 0·6	+ 5·7	+0·3
	11	27·7	+ 9·7	Sunday.	+ 4·9	+ 1·9	−22·5	− 1·7	+ 5·0	+ 1·8	− 4·5	0·0	− 6·4	+ 5·7	−0·6
	12	27·4	Sunday.	+ 3·0	−16·0	+ 7·3	−12·0	− 9·0	Sunday.	+ 0·7	− 3·5	−10·5	+ 3·3	Sunday.	−4·1
	13	27·2	+11·6	− 3·9	− 3·1	+ 7·0	+ 0·1	Sunday.	+ 6·3	+ 4·8	+ 1·1	−16·7	−16·3	+ 1·2	−0·7
	14	27·0	+13·2	− 1·6	+ 7·9	+ 5·6	Sunday.	−10·7	+ 6·0	+10·6	+ 5·1	− 4·1	Sunday.	+ 0·5	+3·3
	15	26·8	+ 7·5	− 1·7	+ 7·6	Sunday.	+ 2·5	−11·3	− 1·2	+ 6·8	+ 7·0	Sunday.	−12·3	+ 0·7	+0·6
	16	26·6	− 4·6	− 5·3	+ 5·9	− 7·7	+ 1·7	− 3·7	− 8·8	+12·8	Sunday.	+ 2·7	−21·8	+ 9·5	−1·8
	17	26·4	−12·9	− 0·9	Sunday.	− 9·3	+ 8·4	− 5·1	− 5·4	Sunday.	+ 3·3	− 9·8	−21·5	+ 1·1	−5·2
	18	26·2	−10·5	Sunday.	+ 4·3	− 7·8	+ 2·2	− 0·2	+ 0·6	+11·2	− 1·1	− 8·4	−10·1	− 0·2	−1·8
	19	26·1	Sunday.	+ 1·1	+ 5·2	− 9·0	−16·1	+ 4·0	Sunday.	+11·4	+10·2	−11·1	− 5·2	Sunday.	−1·1
	20	25·9	−11·2	− 1·8	+ 9·5	− 7·7	−14·4	Sunday.	−14·0	− 0·5	+11·9	− 3·9	−10·5	− 0·3	−3·9
	21	25·8	−17·9	+ 6·8	+ 8·7	+ 1·9	Sunday.	− 4·2	− 6·3	−10·7	+ 2·0	+ 4·8	Sunday.	− 9·1	−2·4
	22	25·7	− 8·5	−15·2	+ 8·8	Sunday.	−11·5	− 5·3	− 4·9	−17·0	+ 0·4	Sunday.	−12·2	− 1·5	−6·7
	23	25·6	+ 8·0	−12·4	+ 8·0	+ 0·4	− 4·9	− 9·8	− 2·7	− 6·6	Sunday.	−14·9	−10·5	+ 7·4	−3·5
	24	25·5	− 0·4	− 7·6	Sunday.	+ 6·0	− 1·8	+ 7·4	− 5·3	Sunday.	− 4·8	−18·5	− 2·1	+13·5	−1·4
	25	25·4	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.	Xmas day.
	26	25·3	Sunday.	+ 5·3	+12·1	+10·4	−10·4	+ 2·6	Sunday.	− 4·2	−12·8	+ 3·2	−24·4	Sunday.	−2·0
	27	25·3	+ 1·4	+ 2·5	+11·2	− 5·1	− 1·0	Sunday.	− 5·1	+ 3·2	− 0·2	+ 1·8	− 0·1	+ 5·5	+1·3
	28	25·2	+ 5·5	+ 1·1	+ 5·9	− 2·4	Sunday.	+ 4·0	+ 9·5	+ 1·5	− 1·3	− 9·5	Sunday.	+ 6·8	+2·1
	29	25·2	+ 3·4	+ 7·4	+ 1·7	Sunday.	+ 8·5	+ 3·9	+15·5	+ 1·7	− 0·5	Sunday.	+11·4	+ 2·1	+5·5
	30	25·2	+ 6·9	− 3·6	+ 1·1	+ 9·3	− 2·0	+11·4	+17·5	+ 1·6	Sunday.	−20·0	+14·0	+ 3·5	+3·6
	31	25·2	− 1·7	− 9·7	Sunday.	+ 8·3	− 3·4	+12·5	+18·6	Sunday.	−10·3	−11·0	+ 7·6	− 1·8	+0·9

With a view of assisting the inquiry whether non-periodic variations of a uniform character manifest a tendency to recur at the same epochs in different years, the daily averages in column 14 of Table IV. have been collected in Table V. into "five-day means," each of the five-day means thus represented being the average non-periodic variation in those five-days in twelve years. And for the purpose of supplying a more satisfactory indication of the degree of variability to which the temperature of any single day is subject at different seasons, than can be obtained by the mere inspection of the differences in columns 2 to 13 of Table IV., the "probable daily non-periodic variation" in column 3 of Table V. has been computed for each of the five-day periods, upon the same principle and by the same process that the "probable error" of each of several partial results is derived from their mutual differences; whilst in column 2 is shown the probable non-periodic variation corresponding to the averages of five days in twelve years contained in column 1, bearing a similar analogy to the probable error of the arithmetical mean of a series of partial results.

TABLE V.

Five-day periods.	Non-periodic variations in twelve years averaged in five-day means.	Probable non-periodic variation in the averages of five days in Column 1.	Probable daily non-periodic variation.	Five-day periods.	Non-periodic variations in twelve years averaged in five-day means.	Probable non-periodic variation in the averages of five days in Column 1.	Probable daily non-periodic variation.
	(1.)	(2.)	(3.)		(1.)	(2.)	(3.)
Jan. 3 to 7 inclusive.	−0°·7	±0°·8	±5°·8	July 3 to 7 inclusive.	−1·5	±0°·5	±3°·4
8 to 12.	−1·1	±0·9	±6·2	8 to 12.	+1·8	±0·6	±4·2
13 to 17.	+2·0	±0·8	±6·1	13 to 17.	+1·1	±0·5	±3·5
18 to 22.	−2·8	±1·1	±7·7	18 to 22.	+1·4	±0·4	±3·1
23 to 27.	+2·0	±0·9	±6·7	23 to 27.	−0·9	±0·4	±3·0
28 to Feb. 1.	−0·7	±1·0	±7·3	28 to Aug. 2.	−2·7	±0·5	±3·7
Feb. 2 to 6.	+1·6	±0·8	±6·0	Aug. 3 to 7.	0·0	±0·4	±2·6
7 to 11.	−1·6	±0·9	±6·3	8 to 12.	+0·2	±0·4	±2·8
12 to 16.	−2·9	±0·9	±6·7	13 to 17.	0·0	±0·4	±3·0
17 to 21.	+1·0	±1·0	±7·0	18 to 22.	−0·7	±0·4	±2·7
22 to 26.	+1·5	±0·9	±6·9	23 to 27.	0·0	±0·4	±3·3
27 to March 3.	−1·4	±0·8	±5·8	28 to Sept. 2.	+2·3	±0·5	±3·6
Mar. 4 to 8.	+2·0	±0·7	±5·0	Sept. 3 to 7.	+1·6	±0·5	±3·4
9 to 13.	+1·8	±0·6	±4·6	8 to 12.	+0·3	±0·7	±4·7
14 to 18.	−1·8	±0·8	±5·6	13 to 17.	−1·8	±0·6	±4·3
19 to 23.	−0·9	±0·7	±5·0	18 to 22.	+0·3	±0·6	±4·2
24 to 28.	+0·9	±0·6	±4·5	23 to 27.	−1·6	±0·6	±4·4
29 to April 2.	−0·6	±0·7	±5·3	28 to Oct. 2.	−0·5	±0·5	±3·7
Apr. 3 to 7.	+0·6	±0·6	±4·0	Oct. 3 to 7.	+1·5	±0·5	±3·6
8 to 12.	−0·1	±0·7	±4·7	8 to 12.	+2·9	±0·5	±3·9
13 to 17.	−1·7	±0·6	±4·6	13 to 17.	−1·3	±0·5	±3·9
18 to 22.	+0·2	±0·6	±4·4	18 to 22.	−1·7	±0·5	±3·9
23 to 27.	+0·5	±0·6	±4·2	23 to 27.	−1·6	±0·5	±3·9
28 to May 2.	−0·2	±0·5	±4·0	28 to Nov. 2.	+1·0	±0·6	±4·9
May 3 to 7.	−0·5	±0·6	±4·3	Nov. 3 to 7.	+0·5	±0·6	±4·3
8 to 12.	+1·1	±0·5	±3·9	8 to 12.	−0·1	±0·6	±4·1
13 to 17.	+1·0	±0·6	±4·0	13 to 17.	+0·8	±0·5	±3·6
18 to 22.	−1·3	±0·6	±4·3	18 to 22.	+0·7	±0·6	±4·2
23 to 27.	+0·3	±0·6	±4·3	23 to 27.	−0·9	±0·7	±4·9
28 to June 2.	−1·2	±0·6	±4·6	28 to Dec. 2.	−2·1	±0·7	±5·3
June 3 to 7.	−0·8	±0·6	±4·4	Dec. 3 to 7.	+1·7	±0·6	±4·4
8 to 12.	−1·9	±0·7	±5·0	8 to 12.	+0·9	±0·8	±5·5
13 to 17.	−0·5	±0·6	±4·6	13 to 17.	−0·8	±0·8	±5·8
18 to 22.	+1·9	±0·5	±3·6	18 to 22.	−3·2	±0·8	±6·0
23 to 27.	+1·3	±0·4	±3·1	23 to 28.	−0·7	±0·9	±5·8
28 to July 2.	+0·3	±0·4	±3·5	29 to Jan. 2.	+2·4	±0·8	±6·1

If we collect the values in column 3 of Table V. into monthly averages, and arrange the months in meteorological seasons, we obtain thereby the following comparison of the probable variability of the daily temperature at different seasons :—

Winter.		Spring.		Summer.		Autumn.	
December	5°·6	March	5°·1	June	4°·0	September	4°·2
January	6·6	April	4·6	July	3·5	October	4·0
February	6·6	May	4·2	August	3·0	November	4·4
Means	6·3		4·6		3·5		4·2

Whence we learn that during the winter months the temperature of a day is as likely to differ from its mean or normal state 6°·3 or *more*, as it is to differ *less* than that amount. Regarding 6°·3 therefore as the *index of variability* in the winter months, the index in the spring months is 4°·6, in the summer months 3°·5, and in autumn 4°·2. The probable variability is a maximum in the last half of January and first half of February, and a minimum in August; it is progressive from the maximum to the minimum and from the minimum to the maximum, and its amount is about twice as great at the maximum as at the minimum.

The principal variations from the general progression shown in the five-day averages of the twelve years, accompanied in each case by the "probable variability," are as follows :—

January 18 to 22 inclusive	−2°·8	±1°·1
February 12 to 16 inclusive	−2·9	±0·9
August 28 to September 2 inclusive	+2·3	±0·5
October 8 to 12 inclusive	+2·9	±0·5
November 28 to December 2 inclusive	−2·1	±0·7
December 18 to 22 inclusive	−3·2	±0·8
December 29 to January 2 inclusive	+2·4	±0·8

Of these, more than half, four, occur in the winter season, two in the autumn, and one in the summer. Their connexion with particular winds and with other meteorological circumstances will be more properly examined in the general discussion of the meteorological observations at Toronto in the volumes of that observatory; but it has appeared desirable to bring into immediate notice the principal instances, furnished by the five-day means in twelve years, of such more considerable departures from the regular progression of the temperature, as may be supposed to indicate in some degree a tendency to periodical recurrence.

For the convenience of those who study *monthly* averages, the mean temperatures of every month in each of the twelve years have been collected in Table VI., together with the average temperature of each month in the whole period. By the comparison of these numbers, the amount by which the temperature of any particular month during the twelve years exceeded or fell short of the average may at once be seen.

February and March appear to be months most liable to extreme variations; July and August the least so; the probable variability of the several months is as follows:—

January	±2°·7	April	±1°·9	July . .	±1°·1	October .	±1°·4
February	±2·6	May .	+1·8	August .	±1·2	November .	±2·1
March .	±2·8	June .	±2·0	September	±1·8	December .	±2·5

The mean *annual* temperature derived from the whole body of the observations in twelve years is 44°·23; and on the supposition that no constant errors, instrumental or observational, or occasioned by insufficient protection or defective exposure of the thermometer, are involved, and that the variations of the temperature in different years may be regarded strictly as accidental oscillations around a mean value, and of equally probable occurrence in every year, the probable error of this result is ±0°·18. The probable variability of a *single year* is ±0°·63; showing that there is an equal probability that the mean temperature of any one year will fall within the limits of 43°·60 and 44°·86, as that it will exceed those limits; a conclusion which perhaps would scarcely have been anticipated considering the great range of the thermometer in the course of the year, and the magnitude of the non-periodic variations in short intervals. The climate of Toronto presents a remarkable combination of great regularity in the annual temperature with great variability occurring in the course of the year. The mean temperatures of the several years differed from the average mean temperature as follows:—

1841.	−0°·31	1844.	+0°·25	1847.	−0°·53	1850.	+0°·22
1842.	−0·27	1845.	+0·35	1848.	+0·85	1851.	−0·25
1843.	−1·88	1846.	+2·13	1849.	−0·14	1852.	−0·39

The excess of cold in 1843 (1°·88) was due chiefly to the occurrence of very low temperatures in February and March of that year; the excess of heat in 1846 (2°·13) was more generally diffused throughout the year, all the months excepting February and October being above their average.

Table VI. exhibits also the normal temperatures of the different months in the geographical latitude, 43° 40′ N., in which Toronto is situated, taken from Dove's 'Verbreitung der Wärme,' Berlin, 1852; as well as the 'Thermic Anomaly,' or differences between these normal values and the temperatures observed at Toronto. It appears from this comparison that every month of the year at Toronto is colder than the normal temperature of the parallel in which it is situated, the mean annual temperature being nearly 7° below the normal. The thermic anomaly is least in July and August (between 2° and 3°) and greatest in February, when it exceeds 11°. Its sudden increase in October and decrease in November are deserving of notice. In viewing the bearing of the thermic anomaly at Toronto on the more general question of the thermic anomaly in the part of North America in which it is situated,

it is necessary to bear in mind that the thermometer at Toronto was about 342 feet above the sea-level, equivalent, as usually estimated, to a diminution of rather more than 1° of Fahr. on account of vertical elevation. Dove's normal temperatures are all reduced to the sea-level, and when the monthly temperatures at Toronto have undergone the same reduction, the thermic anomaly indicated by them is diminished to about 1° in July and August, but in February still reaches the large amount of 10°; in both respects therefore confirming Dove's conclusion, that the summers of North America are *not* warmer than is due to their latitude, whilst the winters are *much* colder.

Table VI.

Showing the mean monthly and annual temperatures in each of the twelve years from 1841 to 1852 inclusive, and the average monthly and annual temperatures in the whole period. Also the mean or normal temperature of the several months in the latitude of 43° 40′ N., taken from Dove's 'Verbreitung der Wärme,' and the 'Thermic Anomaly,' shown by the observations at Toronto.

Years.	January.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean annual temperature.
1841.	25°·6	22°·4	27°·7	39°·2	50°·5	65°·6	65°·0	64°·4	61°·3	41°·6	35°·0	28°·7	43°·92
1842.	27·9	26·9	35·8	43·1	49·1	55·6	64·7	65·7	55·7	45·1	33·3	24·7	43·96
1843.	28·7	14·5	21·3	40·9	49·1	58·4	64·5	66·4	59·1	41·8	33·5	30·0	42·35
1844.	20·2	26·0	31·3	47·5	53·6	59·9	66·0	64·3	58·6	43·3	34·9	28·2	44·48
1845.	26·5	26·0	35·4	42·1	49·6	61·0	66·2	67·9	56·0	46·4	36·8	21·1	44·58
1846.	26·7	20·4	33·1	44·0	55·5	63·3	68·0	68·4	63·6	44·6	41·3	27·5	46·36
1847.	23·3	21·5	26·2	39·2	54·4	58·4	68·0	65·1	55·6	44·0	38·6	30·1	43·70
1848.	28·7	26·6	28·6	41·3	54·1	62·9	65·5	69·2	54·2	46·3	34·5	29·1	45·08
1849.	18·5	19·5	33·5	39·0	48·0	63·2	68·4	66·3	58·2	45·3	42·6	26·5	44·09
1850.	29·7	26·0	29·8	37·9	47·6	64·3	68·9	66·8	56·5	45·4	38·8	21·7	44·45
1851.	25·5	27·6	32·4	41·3	51·3	59·2	65·0	63·6	60·0	47·4	32·9	21·5	43·98
1852.	18·4	23·4	27·7	38·2	51·4	60·8	66·8	65·9	57·5	48·0	36·0	31·9	43·84
Means in 12 years.	24·97	23·40	30·23	41·14	51·18	61·05	66·41	66·16	58·02	44·93	36·51	26·75	44·23
Normal temperatures in latitude 43° 40′ N.	32·8	34·7	40·1	50·2	58·1	64·6	68·7	68·5	61·5	53·8	43·2	36·0	51·0
'Thermic Anomaly' at Toronto.	−7·8	−11·3	−9·9	−9·1	−6·9	−3·5	−2·3	−2·3	−3·5	−8·9	−6·7	−9·2	−6·8

Plate XI. represents the five-day means in the twelve years, both as computed from the monthly means, and as given by the actual averages of every five days; the darker line shows the computed and the fainter line the observed five-day means. The darker line consequently shows the mean march of the temperature, the fainter

line its actual march, and their difference the non-periodic variations for intervals of five days. The monthly means are distinguished by a small circle drawn around the point which marks the temperature; they are connected by faintly dotted vertical lines with the monthly means (similarly distinguished) of the normal temperatures of the latitude of Toronto, derived by Dove from the mean monthly temperatures of thirty-six equidistant points in each of the parallels of 40° and 50° as shown by his isothermal maps. The normal temperature corresponds to the level of the sea; the temperatures at Toronto are those given directly by the observations, uncorrected for the elevation, which, as already stated, is about 342 feet above the sea.

VI. *On Periodical Laws in the larger Magnetic Disturbances.*

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Received February 16, 1853,—Read February 24, 1853.

HAVING submitted the hourly observations of the magnetic declination made at the St. Helena and the Cape of Good Hope Observatories to a course of examination similar to that undertaken by Colonel SABINE for Toronto and Hobarton, and published by him in the Philosophical Transactions, Part I. for 1851, and Part I. for 1852, also in Vol. II. Magnetical and Meteorological Observations at Hobarton, and Vol. II. Magnetical and Meteorological Observations at Toronto (now in the press), with the object of investigating some of the laws which govern the occurrence of the larger magnetic disturbances, I have found that at these two stations, as well as at the two others, the evidence is complete of the existence of laws of a periodical character: the facts appear to be important materials towards elucidating the general laws of disturbances, and I therefore venture to communicate them to the Royal Society.

The observations which have been examined are comprised between September 1842 and September 1847 at St. Helena, and between July 1841 and July 1846 at the Cape of Good Hope; these periods include all the hourly observations that could be made available for discussion.

The observations were made simultaneously at all the magnetic stations, viz. at the commencement of each Göttingen hour; we have, therefore, the best opportunity of judging of the degree in which the disturbances may be referred to one general cause, while by arranging them with regard to local time, the means are afforded of showing the operation of laws which have respect to the sun's position towards the place, both in relation to the hour of the day and the season of the year.

At St. Helena, every observation that differed by 2·5 scale divisions from its normal place (meaning by that, the mean place at the hour, and in the month in which the observation occurs) has been regarded as a disturbed observation, and separated from the others; the number of observations thus separated amounts to 2659; the whole number of hourly observations made in the period amounted to 36,054, wherefore one observation in 13·6 has been regarded as disturbed. At the Cape, in like manner, every observation that differed by more than 2·5 scale divisions has been regarded as disturbed and separated from the others; the number of separated observations is 3038, the number of hourly observations made in the period is 36,571, wherefore one observation in every 12·0 is disturbed.

The limit beyond which an observation should be regarded as disturbed, was, of course, arbitrarily fixed; and as the principle on which the disturbances were separated was the same as that which formed a guide in the previous investigation, it is only necessary here to repeat, that the absolute numbers which express the frequency and amount of the disturbances cannot be compared at any two stations, but a comparison may with propriety, and has been made, between the ratios of each year, or season or hour, to the respective mean quantities.

In a paper by Colonel Sabine already alluded to, a comparison has been instituted of the disturbances at Toronto and Hobarton, stations almost as far from each other, geographically, as it is possible for two places to be situated on the surface of the earth, but possessing considerable analogy in their magnetical relations. The result of the comparison was to show a striking connection between the two places in the laws of the occurrence of disturbances, whether as regards the hour of the day, the season of the year, or the year itself. Now St. Helena and the Cape of Good Hope, situated near together, are unlike magnetically, as well as in geographical position, to either Toronto or Hobarton; and I am desirous, in addition to presenting an investigation into the periodical character of the laws of disturbance operating at the new stations, to point out in what respect the character agrees, and in what it differs, from that which has been found at Toronto and Hobarton.

We may expect, from facts already known, some agreement in the amount of disturbance in the same years at different places. Table I. exhibits the ratios of the numbers and aggregate values of the disturbed observations in the different years to the average annual number and aggregate value, also the average value of one disturbance in each year.

Table I.

Years.	St. Helena.			Cape of Good Hope.		
	Numbers.	Aggregate values.	Average value of one disturbance.	Numbers.	Aggregate values.	Average value of one disturbance.
1841	.....	.....	.....	0·97*	1·07*	3·10*
1842	0·98†	0·96†	2·43†	1·25	1·26	2·86
1843	0·82	0·76	2·31	0·57‡	0·53‡	2·62‡
1844	0·90‖	0·90‖	2·47‖	0·90	0·88	2·76
1845	1·00	0·97	2·41	0·93	0·91	2·76
1846	1·06	1·03	2·42	1·38§	1·36§	2·78§
1847	1·25¶	1·37¶	2·72¶	.....	.....	.....

The observations are here too incomplete, and their duration too limited to derive more than a general indication of the action of the same law, which has been shown to exist at Toronto and Hobarton, of the periodical character of the number and magnitude of the disturbances during a cycle of years; both at Toronto and Hobarton

* From six months' observations. † From four months' observations. ‡ From ten months' observations.
‖ From ten months' observations. § From six months' observations. ¶ From eight months' observations.

the year 1843 has been shown to be that of least disturbance, and 1848 of greatest; and we have here some additional evidence of a general cause operating over the whole globe to produce a minimum magnetic effect in 1843 progressing towards a maximum in 1848. In judging of the fulfilment of the general law and of the degree of accordance of the ratios at the two stations, it is to be borne in mind that three years only are complete years of observation at each station, and that in the other three years at each station the ratios are necessarily computed from the portions of those years to which the observations are limited; also, that although the observations were everywhere made simultaneously, as stated above, yet that the cessation on Sundays was regulated by local time; and as the Saturdays' observations were closed at midnight, and the Mondays' observations commenced at 1 A.M. civil time, there are a certain number at each station which have none corresponding at any other.

Table II. contains the ratios of the numbers and aggregate values of the disturbances, divided into their westerly and easterly components, to the average annual number and aggregate value.

TABLE II.

Years.	St. Helena.				Cape of Good Hope.			
	Westerly.		Easterly.		Westerly.		Easterly.	
	Numbers.	Aggregate values.	Numbers.	Aggregate values.	Numbers.	Aggregate values.	Numbers.	Aggregate values.
1841	.....	.....	.....	.....	0·95	1·07	1·00	1·08
1842	0·91	0·92	1·02	0·96	1·14	1·16	1·39	1·40
1843	0·75	0·70	0·89	0·86	0·56	0·52	0·59	0·54
1844	0·89	0·91	0·90	0·92	0·97	0·95	0·80	0·77
1845	0·96	0·94	1·03	1·04	0·96	0·96	0·88	0·84
1846	1·07	1·04	1·02	1·05	1·42	1·36	1·36	1·36
1847	1·43	1·49	1·14	1·17	.....	.....	.....	.....

If we separate the whole number of observations at St. Helena and the Cape into their easterly and westerly components, we find that each of the two divisions singly, indicate the same periodical law which they did when combined, viz. a fall to a minimum in 1843, from whence an increase towards a maximum in 1848 takes place; and this is apparent both in the number of observations disturbed and the amount of the disturbance. By an easterly disturbance is to be understood, that the end of the needle which points north is disturbed from its normal place towards the east, and *vice versâ*, and this whether the mean declination has an easterly or westerly value, and whether the station be in the northern or southern hemisphere.

Table III. contains the ratios of the westerly to the easterly disturbed observations in each year, in numbers and values.

TABLE III.

Years.	St. Helena.		Cape of Good Hope.	
	Numbers. W. to E.	Values. W. to E.	Numbers. W. to E.	Values. W. to E.
1841	.....	.....	1·36 to 1	1·42 to 1
1842	1·12 to 1	1·28 to 1	1·17 to 1	1·19 to 1
1843	1·07 to 1	1·09 to 1	1·35 to 1	1·38 to 1
1844	1·26 to 1	1·45 to 1	1·73 to 1	1·77 to 1
1845	1·18 to 1	1·20 to 1	1·57 to 1	1·66 to 1
1846	1·33 to 1	1·34 to 1	1·51 to 1	1·40 to 1
1847	1·60 to 1	1·70 to 1	.....	.....

The westerly disturbances therefore decidedly preponderate at both stations over the easterly in the aggregate of each year, both in frequency and amount. At Hobarton a similar preponderance of westerly over easterly was found in every year; but at Toronto, on the contrary, the easterly disturbance exceeded the westerly in every year (though they were nearly equal in 1841 and 1847); yet on the average of seven and a half years' observation the easterly disturbances were in proportion to the westerly, as 1·17 to 1 in number, and as 1·16 to 1 in value.

Dividing the disturbances into the several months of their occurrence, we have in Table IV. the ratios in each month of the number of disturbances, of their values, and of the average value of one disturbance to the mean monthly values.

TABLE IV.

Months.	St. Helena.			Cape of Good Hope.		
	Numbers.	Values.	Average value of one disturbance.	Numbers.	Values.	Average value of one disturbance.
January	1·60	1·76	1·12	1·71	1·77	1·04
February ...	1·39	1·41	1·03	1·49	1·60	1·08
March	0·99	1·00	1·02	0·95	0·90	0·95
April	1·36	1·41	1·05	1·36	1·29	0·96
May	0·83	0·80	0·97	0·51	0·48	0·94
June	0·36	0·34	0·97	0·42	0·37	0·88
July	0·64	0·59	0·94	0·49	0·58	1·18
August	0·75	0·72	0·97	0·48	0·47	0·96
September ...	1·21	1·20	1·01	0·91	0·91	1·00
October	0·76	0·71	0·95	1·14	1·09	0·96
November ...	0·96	0·91	0·96	1·32	1·32	1·00
December ...	1·13	1·14	1·02	1·21	1·23	1·01

From this table we find that January is the month of greatest disturbance in frequency and value, and June of least disturbance, both at St. Helena and the Cape. On referring to the Hobarton observations, the very same months are found to be those of greatest and least disturbance respectively, but at Toronto *both* January and June are months of minimum disturbance; the maximum disturbances in the year occurring at Toronto in April and September.

In comparing the observations at Toronto and Hobarton alone, it was found that

although a minimum of disturbance occurred at Toronto in midsummer, still the disturbances in the four summer months had a considerable preponderance over the disturbances in the four winter months; at Hobarton also the disturbances in the four summer months greatly exceeded those in the four winter months, and it seemed reasonable to refer the maxima and minima periods of disturbance in their *mean effects* to extreme seasons; St. Helena however offers a remarkable objection. The sun is vertical at St. Helena early in November, and again early in February, but there is no indication of the occurrence of the disturbances being connected with the sun's position relative to the place. The temperature reaches its maximum in the middle of March, and its minimum early in September; and if we consider the periods of extreme temperature to be those of extreme seasons at St. Helena, we shall find that at *both* those times the disturbances have their mean value, proving that insofar as St. Helena has extreme seasons, they are undoubtedly not coincident with extreme disturbances. While, therefore, we can class St. Helena, Cape of Good Hope and Hobarton together, places differing so widely in climate and geographical position, as exhibiting their maximum and minimum disturbance in the same months of the year contrasted with Toronto as presenting a different law, we may conclude that the principal causes which operate in producing the annual variation of the disturbances are not dependent upon local seasons.

There is, however, a striking point of similarity at all the stations about the times of the sun's passing the equator. At Toronto, April and September are both months of maxima disturbance in the year, September being that of primary maximum. At St. Helena a distinct tendency towards maxima is shown in the same two months, rather more strongly marked in April than in September. At the Cape of Good Hope the tendency towards maxima in the same two months is also quite apparent, but still more strongly marked in April over September than at St. Helena. At Hobarton the tendency to maxima in April and September is likewise evident, though not so marked, and here, as at Toronto, September's maximum preponderates over that of April.

The average value of a single disturbance scarcely differs in any of the months, either at St. Helena or the Cape; at Toronto and Hobarton the average value of one disturbance appears to be least in their summer months, about a mean in winter, and greatest in the equinoctial months.

Table V. contains the ratios of the numbers and values of the westerly to the easterly disturbances in the different months. The westerly disturbances exceed the easterly in every case; the preponderance has its greatest excess in the month of May, and its least in the month of February at both stations. It also appears that the ratio of westerly *values* is greater than the ratio of westerly *numbers*. At Hobarton the westerly tendencies were also found to exceed the easterly in every month, while at Toronto the easterly exceeded the westerly in every month; and it is worthy of remark, that at these two stations, as well as at the Cape and St. Helena, the ratios of *values* likewise exceeded the ratios of *numbers*; the amount in every instance is small, but decided.

TABLE V.

Ratios of Westerly to Easterly disturbed observations in every month in the year in numbers and values, at St. Helena and the Cape of Good Hope, the numbers and values of the easterly disturbances being represented in each case by unity.

Months.	St. Helena.		Cape of Good Hope.	
	Numbers.	Values.	Numbers.	Values.
January	1·23	1·18	1·16	1·14
February.....	0·96	1·03	1·21	1·22
March.....	1·21	1·20	1·90	2·03
April	1·41	1·56	1·39	1·50
May	1·88	2·07	3·13	3·20
June	1·13	1·07	2·09	1·99
July	1·70	1·63	1·70	1·55
August	1·11	1·17	1·20	1·44
September ...	1·24	1·34	1·54	1·55
October	1·15	1·28	1·28	1·26
November ...	1·50	1·55	1·43	1·49
December ...	1·18	1·28	1·31	1·43
Means.....	1·31	1·37	1·61	1·65

Table VI. exhibits the average value of an easterly compared with that of a westerly disturbed observation in the several months, found by dividing the aggregate easterly or westerly amount of disturbance by the corresponding number of occurrences.

TABLE VI.

Average values of an Easterly and of a Westerly disturbance in the several months.

Months.	St. Helena.		Cape of Good Hope.	
	Easterly.	Westerly.	Easterly.	Westerly.
January	2·67	2·89	2·93	2·88
February ...	2·35	2·54	3·01	3·03
March	2·43	2·43	2·55	2·70
April	2·38	2·62	2·55	2·75
May	2·18	2·40	2·57	2·64
June	2·37	2·25	2·55	2·43
July	2·31	2·22	3·48	3·18
August	2·24	2·36	2·42	2·91
September ...	2·30	2·50	2·78	2·79
October	2·15	2·39	2·69	2·66
November ...	2·24	2·34	2·73	2·85
December ...	2·32	2·52	2·69	2·94
Means.....	2·33	2·45	2·75	2·81

It appears from this table that an easterly disturbance is very generally less in amount than a westerly disturbance. At St. Helena there is but one month in the year in which the westerly disturbance falls below the easterly, and but three at the

Cape of Good Hope. On the average of the year the easterly is decidedly a smaller disturbance than the westerly. The same fact is shown from the Hobarton observations. At that station the easterly disturbance is smaller than the westerly in eleven months of the year, the average annual easterly disturbance being considerably less than the westerly. At Toronto also we find the same fact occurring; the value of a disturbed easterly observation is less than a westerly on the average of the year; the difference is however in this case inconsiderable, and there are several discrepancies in the different months.

Next, distributing the disturbances into the several hours of their occurrence, the following table is obtained. The facts, besides being very remarkable when viewed alone, acquire so much additional interest when exhibited in contrast with the law which has already been shown to prevail at Toronto and Hobarton, that I have placed the corresponding tables of the ratios at Toronto and Hobarton beside those of St. Helena and the Cape for the sake of more convenient comparison.

Table VII.

Ratios of the numbers and of the aggregate values at the several hours, to the mean hourly numbers and values at St. Helena, Cape of Good Hope, Hobarton and Toronto.

Mean time at station, Astronomical reckoning.	St. Helena.		Cape of Good Hope.		Hobarton.		Toronto.	
	Numbers.	Values.	Numbers.	Values.	Numbers.	Values.	Numbers.	Values.
Day.								
18 hours.	0·23	0·24	0·98	1·00	0·73	0·68	1·04	1·08
19	0·44	0·38	1·30	1·29	1·01	0·96	1·02	1·28
20	0·95	0·88	1·97	1·86	1·12	1·07	1·06	1·14
21	1·58	1·49	2·01	1·97	1·05	0·91	1·08	1·09
22	1·92	1·94	2·25	2·28	1·02	0·85	1·06	0·92
23	2·49	2·55	2·12	2·17	1·04	0·88	1·01	0·83
Noon.	2·70	2·77	1·97	1·93	1·04	0·85	0·86	0·67
1	2·82	2·92	1·57	1·51	1·11	0·90	0·72	0·55
2	2·65	2·72	1·31	1·22	1·14	0·97	0·59	0·49
3	2·29	2·27	0·83	0·76	1·04	0·91	0·66	0·52
4	1·86	1·78	0·77	0·69	1·00	0·91	0·69	0·58
5	1·18	1·10	0·52	0·48	0·90	0·86	0·69	0·60
Sum of ratios at day-hours.	21·11	21·04	17·60	17·16	12·20	10·75	10·48	9·75
Night.								
6 hours.	0·60	0·56	0·63	0·60	1·04	0·90	0·77	0·78
7	0·29	0·29	0·67	0·66	0·81	0·86	0·92	0·89
8	0·32	0·32	0·71	0·81	0·88	0·93	1·11	1·17
9	0·22	0·26	0·62	0·65	0·98	1·17	1·26	1·48
10	0·21	0·24	0·59	0·69	1·11	1·26	1·27	1·33
11	0·20	0·24	0·44	0·53	1·35	1·66	1·15	1·15
Midnight.	0·22	0·26	0·45	0·52	1·28	1·45	1·21	1·24
13	0·15	0·16	0·52	0·52	1·10	1·12	1·24	1·35
14	0·17	0·18	0·49	0·50	0·99	1·15	1·21	1·21
15	0·16	0·15	0·44	0·42	1·01	1·08	1·15	1·12
16	0·15	0·17	0·51	0·49	0·95	0·94	1·22	1·25
17	0·17	0·18	0·44	0·45	0·60	0·64	1·16	1·26
Sum of ratios at night-hours.	2·86	3·01	6·51	6·84	12·10	13·16	13·67	14·23

The above table shows in a very striking manner that at St. Helena the disturbances are almost, without exception, confined to the hours of the day. At the Cape the hours of the day are likewise those of greatest disturbance in a very marked degree, as for instance, at eleven o'clock in the forenoon they are between four and five times as frequent, and as great in amount, as at the corresponding hour at night twelve hours later. Hobarton and Toronto present however very different features: there the hours of the *night* are of greatest disturbance; but it will be seen that the sum of the ratios at the twelve hours of the night does not exceed the sum of the ratios in the twelve hours of the day in the same degree that the sum of the day ratios exceeds the sum of the night ratios at St. Helena and the Cape. At Hobarton the night ratios only *slightly* exceed those of the day. At Toronto the preponderance is greater; but at the Cape we find the day-ratios between two and three times as great as those of the night, and at St. Helena about seven times as great. We must proceed further to gain a more perfect knowledge of the laws of the daily and nightly occurrences, by separating the disturbances classed according to the hours of their occurrence into their easterly and westerly components.

Table VIII.

Ratios of the Easterly and Westerly numbers and values at the several hours, to the mean easterly and westerly numbers and values.

Mean time at the station, Astronomical reckoning.	St. Helena.				Cape of Good Hope.			
	Easterly.		Westerly.		Easterly.		Westerly.	
	Numbers.	Values.	Numbers.	Values.	Numbers.	Values.	Numbers.	Values.
Day.								
18 hours	0·08	0·08	0·34	0·36	1·10	1·19	0·91	0·86
19	0·39	0·32	0·48	0·43	1·56	1·56	1·12	1·10
20	1·08	0·99	0·85	0·80	2·29	2·28	1·74	1·57
21	1·65	1·62	1·52	1·40	2·25	2·32	1·84	1·73
22	2·12	2·22	1·76	1·73	2·60	2·77	2·00	1·94
23	2·80	2·96	2·24	2·24	2·56	2·67	1·81	1·82
Noon.	3·00	3·12	2·47	2·50	2·27	2·29	1·76	1·68
1	3·02	3·17	2·66	2·73	1·79	1·82	1·42	1·29
2	3·06	3·19	2·32	2·37	1·54	1·49	1·15	1·03
3	2·59	2·61	2·05	2·02	0·92	0·89	0·76	0·66
4	2·16	2·07	1·61	1·56	0·63	0·59	0·86	0·76
5	1·08	0·98	1·26	1·18	0·42	0·34	0·60	0·58
Sum of ratios at day-hours.	23·03	23·33	19·56	19·32	19·93	20·21	15·97	15·02
Night.								
6 hours	0·41	0·35	0·76	0·71	0·42	0·38	0·77	0·75
7	0·14	0·12	0·40	0·43	0·31	0·24	0·92	0·96
8	0·12	0·10	0·47	0·49	0·29	0·22	1·01	1·21
9	0·06	0·05	0·34	0·41	0·23	0·19	0·89	0·97
10	0·04	0·03	0·34	0·39	0·23	0·20	0·84	1·03
11	0·00	0·00	0·35	0·41	0·17	0·16	0·64	0·78
Midnight.	0·00	0·00	0·39	0·45	0·23	0·24	0·61	0·71
13	0·00	0·00	0·27	0·28	0·40	0·41	0·60	0·60
14	0·02	0·02	0·29	0·31	0·44	0·37	0·53	0·59
15	0·04	0·04	0·26	0·24	0·44	0·40	0·45	0·44
16	0·00	0·00	0·27	0·29	0·54	0·48	0·49	0·50
17	0·02	0·02	0·29	0·31	0·46	0·50	0·43	0·42
Sum of ratios at night-hours.	0·85	0·73	4·43	4·72	4·16	3·79	8·18	8·96

Separating the whole body of disturbances at St. Helena and the Cape of Good Hope into their easterly and westerly components, it is thus found that the law of the hourly disturbance has the same general characteristic feature when viewed separately in either direction as when together, viz. the preponderance of disturbances during the day over those during the night. This would be anticipated from the large excess of the total daily disturbances; but the fact is interesting as evidencing a law different from that by which the disturbances both at Toronto and Hobarton are regulated. When the disturbances at these places were separated into their easterly and westerly components, it was found that for the purpose of comparison they should be arranged into two classes, viz. the easterly disturbances at Toronto and the westerly at Hobarton into one class, and the westerly disturbances at Toronto and the easterly at Hobarton into another; the results are elsewhere published in detail*, but it may be convenient here to repeat the general conclusion, viz. as respects the first class (easterly at Toronto and westerly at Hobarton), it was found that, at Toronto, the nightly disturbances were to the daily as 2·0 to 1 in number and as 2·8 to 1 in value. At Hobarton the nightly disturbances were to the daily as 1·6 to 1 in number and as 2·4 to 1 in value, the disturbance being greater at both places at *any* hour of the night than at *any* hour of the day. Respecting the second class (westerly at Toronto and easterly at Hobarton), the period of twenty-four hours required to be otherwise divided. At Toronto (westerly) the numbers and values were uniformly less at every hour from noon to midnight than at *any* hour from midnight to noon. At Hobarton (easterly) the numbers and values were greater at *any* hour from 6 A.M. to 5 P.M. than at *any* hour from 6 P.M. to 5 A.M., or the easterly *day* disturbance greater than the easterly *night* disturbance. In this last we recognize a similarity in the law to that in both directions combined, or either separately, at the Cape and St. Helena; and although we found that the *total* disturbance at Hobarton showed a preponderance during the night to that during the day, it is evident this was caused by the westerly maxima having overridden and masked the easterly maxima.

It has already been shown, as the result of the separation of the disturbances at St. Helena and the Cape into easterly and westerly movements, that in each separate instance, as in both combined, there is the same general law, viz. the maxima of frequency and amount occurring in the day hours and the minima in the night hours. When closely followed out, however, the law of easterly and westerly disturbances presents some differences. Table IX. contains the total amounts of easterly and of westerly disturbances observed during all the years in which the observations under discussion were made, in frequency and value, at the several hours of their occurrence at St. Helena and the Cape of Good Hope.

* Philosophical Transactions for 1852, p. 103.

Table IX.

Mean time at Station, Astronomical reckoning.	St. Helena.				Cape of Good Hope.			
	Numbers.		Values.		Numbers.		Values.	
	Easterly.	Westerly.	Easterly.	Westerly.	Easterly.	Westerly.	Easterly.	Westerly.
Day.								
19 hours.	19	30	52·6	91·7	81	83	301·4	308·1
20	53	53	160·7	171·9	119	129	440·0	440·4
21	81	94	261·2	301·6	117	136	447·9	484·2
22	104	109	357·5	372·3	135	148	533·7	544·6
23	137	139	479·0	481·7	133	134	515·1	510·8
Noon.	147	153	503·2	539·2	118	130	441·5	470·8
1	148	165	511·0	589·7	93	105	350·3	361·3
2	150	144	515·1	510·8	80	85	287·9	289·6
3	127	127	420·4	436·3	48	56	171·2	185·9
4	106	100	333·4	336·2	33	64	114·1	212·9
5	53	78	158·3	255·1	22	44	66·4	161·9
6	20	47	55·7	153·9	22	57	72·7	211·1
Night.								
7 hours.	7	25	19·2	91·8	16	68	46·2	267·9
8	6	29	16·4	105·8	15	75	42·4	338·6
9	3	21	7·8	89·4	12	66	35·9	271·1
10	2	21	5·1	83·7	12	62	37·6	289·3
11	0	22	0·0	89·9	9	47	31·0	218·7
Midnight.	0	24	0·0	96·3	12	45	47·2	199·6
13	0	17	0·0	61·0	21	44	78·7	167·8
14	1	18	2·8	66·6	23	39	70·6	166·5
15	2	16	6·2	50·7	23	33	76·0	123·2
16	0	17	0·0	62·6	28	36	92·0	140·0
17	1	18	2·5	65·9	24	32	96·8	115·8
18	4	21	12·4	77·0	57	67	229·5	241·4

From this table it appears that at St. Helena, although few disturbances occurred at night in comparison with those during the day, almost all the nightly disturbances were in the westerly direction. During five years of observation 183 disturbances, in all, occurred between the hours of 9 P.M. and 5 A.M. inclusive, having a value of 690·5 scale divisions; of these but nine were in the easterly direction with a value of only 24·4 scale divisions, the remaining 174 were in the westerly direction with a value of 666·1 scale divisions. During the same number of hours of maximum disturbance, from 9 A.M. to 5 P.M. inclusive, there were 2162 disturbances having a value of 7362·0 scale divisions; of these 1053 were to the east and 1109 to the west, the values being 3539·1 and 3822·9 scale divisions respectively; westerly are therefore slightly the greater. At the Cape of Good Hope the preponderance of westerly over easterly disturbance is greater during the day hours than at St. Helena, and not so great during the night hours; and the analogy with St. Helena is still so far carried out that the excess during the night hours is considerably greater than the excess in the day hours.

St. Helena is situated in that part of the globe in which the diurnal movement of the declination needle has peculiar interest. Unlike those places in middle lati-

tudes, where the north end of the needle attains its extreme easterly and westerly positions at the same hours in all seasons, at St. Helena the curve of diurnal movement is precisely reversed at opposite periods of the year; in general terms, it may be said to correspond to that of the diurnal variation in the northern hemisphere, (at Toronto for example), when the sun is north of the equator, and to the diurnal variation in the southern hemisphere (or as at Hobarton), when the sun is south of the equator. It appeared therefore desirable to examine whether the law of the occurrence of the disturbance, as respects the hour of the day, remained the same in every month in the year, whether in fact there was any analogy between the law of hourly disturbance at one period of the year compared with northern latitudes, or at Toronto, and of the opposite period compared with southern latitudes, or at Hobarton.

Table X. will show that the law is the same in all the months of the year, the hours of the day being in every month periods of greatest, and the night hours of least disturbance.

Table X.

Monthly Statement of the number of Disturbed Observations in Five Years, at St. Helena, distributed into the several months and hours of their occurrence.

	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Sums.
Hours.													
Noon.	34	30	28	42	16	11	32	19	25	13	20	30	300
1	26	24	29	42	25	12	32	19	34	19	23	28	313
2	29	31	20	35	20	12	21	22	37	12	27	28	294
3	28	30	18	23	23	10	25	13	29	12	17	26	254
4	28	22	18	18	16	6	21	12	21	12	14	18	206
5	16	10	14	12	8	5	9	9	16	10	11	11	131
6	7	5	8	7	5	0	6	6	3	3	6	11	67
7	3	2	4	8	1	1	3	1	2	0	4	3	32
8	3	1	5	6	3	2	3	3	1	2	3	3	35
9	4	1	3	6	2	1	1	2	0	0	2	2	24
10	4	2	2	6	2	0	1	3	0	0	1	2	23
11	3	1	3	6	2	0	2	1	0	0	2	2	22
Midnt.	3	2	2	6	3	0	2	0	0	0	2	4	24
13	1	2	2	4	0	0	2	0	1	1	2	2	17
14	1	2	2	2	1	0	3	0	1	2	3	2	19
15	2	1	1	2	1	0	2	3	1	1	3	1	18
16	3	2	0	2	1	1	1	2	1	1	3	0	17
17	3	1	0	2	0	0	4	1	1	2	5	0	19
18	3	1	0	2	2	1	2	3	3	2	5	1	25
19	5	2	1	2	1	2	5	3	11	10	5	2	49
20	15	8	8	9	4	1	5	6	26	15	4	5	106
21	22	15	12	16	18	4	9	10	26	14	13	16	175
22	27	24	17	18	17	5	17	11	15	19	18	25	213
23	27	38	25	28	16	7	25	20	17	20	22	31	276
Sums.	297	257	222	304	187	81	233	169	271	170	215	253	2659

It now only remains to notice the influence of the disturbances on the mean position of the magnet at the different hours; this we shall determine by obtaining the aggregate excess of disturbance in one direction over that in the opposite direction,

and dividing by the whole number of days over which the period of observation extends.

Table XI. contains the excess of easterly or westerly values of the disturbances at the several hours, and the mean effect on the position of the magnet.

TABLE XI.

Mean time at Station, Astronomical reckoning	St. Helena.	Cape of Good Hope.
	Mean diurnal variation occasioned by the disturbed observations.	
18 hours	0·31 W.	0·06 W.
19	0·18 W.	0·03 W.
20	0·05 W.	0·02 W.
21	0·19 W.	0·18 W.
22	0·07 W.	0·05 W.
23	0·01 W.	0·02 E.
Noon.	0·17 W.	0·14 W.
1	0·37 W.	0·05 W.
2	0·02 E.	0·01 W.
3	0·08 W.	0·08 W.
4	0·01 W.	0·49 W.
5	0·46 W.	0·49 W.
6	0·46 W.	0·68 W.
7	0·34 W.	1·09 W.
8	0·43 W.	1·46 W.
9	0·38 W.	1·16 W.
10	0·37 W.	1·24 W.
11	0·43 W.	0·92 W.
13	0·46 W.	0·75 W.
Midnight.	0·29 W.	0·44 W.
14	0·30 W.	0·47 W.
15	0·21 W.	0·23 W.
16	0·30 W.	0·23 W.
17	0·30 W.	0·09 W.

The effect of the disturbances in its mean quantity is therefore *constantly* to draw the north end of the magnet to the west both at St. Helena and the Cape; there is but one exceptional hour at St. Helena and one at the Cape, and these from the smallness of the amount may perhaps be considered as accidental; the influence on the night hours is decidedly greater than in the day, at both places, and is more strongly marked at the Cape than at St. Helena. Once more comparing this law with that at Toronto and Hobarton, it is interesting to observe, that whereas we have just seen the mean effect of the disturbance is constant in drawing the north end of the magnet to the west in every hour of the twenty-four at the Cape and St. Helena, and more energetically in the night than in the day; at Toronto the effect is west during the day and east during the night; and at Hobarton east during the day and west during the night.

In the foregoing paper exact numerical results have not been aimed at. It would be difficult, even if instrumental means were more perfect, to arrive at a very precise

knowledge of the normal positions of the magnet, and therefore to separate *all* the disturbances, including those of smallest amount; nor would any commensurate advantage be gained by the attempt.

By the method pursued a sufficient body of disturbances has been dealt with (and those of the larger amount) to make it probable that the numerical ratios would suffer little alteration by a more refined process, which it is doubtful the observations themselves would sustain. The nature of the laws has in every instance been indicated; and their regular and systematic character, evidenced in the classification adopted, bear abundant testimony that the method (first employed by Colonel SABINE) of separating observations that differ by a certain prescribed amount from the mean, and dealing with them as disturbances, is the true method of investigating the laws by which the abnormal fluctuations are regulated.

Woolwich, February 15*th*, 1853.